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Demography and control of *Cirsium vulgare* (Savi) Ten. in relation to grazing

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Summary: Résumé: Zusammenfassung

Cirsium vulgare (Savi) Ten. is a serious biennial alien weed only in pasture land in Australia. To identify reasons for such preferential infestation and to isolate sensitive stages in the life history of *C. vulgare*, comparative demographic analyses were conducted in grazed, ungrazed and herbicide-treated Mediterranean-like pastures in south-eastern Australia. Grazing by sheep (i) reduced competition from neighbouring plants, (ii) increased *C. vulgare* growth, flowering and seed (achene) production, and (iii) promoted survival of *C. vulgare* seedlings. The most sensitive period in the life of *C. vulgare* appears to be the transition from the seedling to rosette life stages where, for example, an average survival rate of only 0·2 and 1·0% occurred in ungrazed and grazed pastures, respectively. In contrast, 10 and 15% of seeds successfully emerge on average as seedlings, and 49 and 51% of rosettes successfully develop into adult plants. Control of *C. vulgare* with dicamba was most effective just after initiation of autumn rainfall. This time corresponds to the period of naturally high seedling mortality in *C. vulgare* induced by competition from neighbouring plants.

Démographie de Cirsium vulgare *(Savi) Ten. et sa maîtrise par rapport au pâturage*

Cirsium vulgare (Savi) Ten. est une mauvaise herbe bisannuelle en Australie, d'origine étrangère, mais elle n'est importante que dans les pâtures. Dans le but de déterminer les raisons de cette préférence et d'établier les stades sensibles dans le cycle de *C. vulgare*, des analyses démographiques ont été entreprises au sud-est de l'Australie dans des pâtures de type méditerranéen. Le pâturage des moutons a diminué la concurrence des plantes voisines, rendu plus importantes la croissance de *C. vulgare* ainsi que sa floraison et la production de graines (akènes) et favorisé la survie des jeunes plants adventices. Il parait que le stade le plus sensible de la vie de *C. vulgare* est la période de transition du stade jeune plant au stade rosette, où le taux moyen de survie était de 0,2% sans et 1% avec pâturage. Par contre, une levée de 10 et 15% des graines a été constatée et 49 et 51% des rosettes deviennent des plantes adultes. Le dicamba s'est montré le plus efficace contre *C. vulgare* en application juste après le commencement des pluies d'automne, époque d'une forte mortalité naturelle parmi les jeunes plants, provoquée par la concurrence des plantes voisines.

Populationsdynamik und Bekämpfung von Cirsium vulgare *(Savi) Ten. unter Bezug auf Beweidung*

Cirsium vulgare tritt in Australien nur in Weideland als wichtiges, zweijähriges, adventives Unkraut auf. Um Ursachen für die selektive Besiedelung von Grasland und um empfindliche Entwicklungsstadien im Entwicklungszyklus herauszufinden, wurden in SO-Australien vergleichende populationsdynamische Untersuchungen in beweidetem, unbeweidetem und mit Herbiziden behandeltem Grasland von mediterranem Typus durchgeführt. Die Beweidung durch

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Schafe hatte zur Folge, dass (i) die Konkurrenz durch benachbarte Pflanzen verringert, (ii) das Wachstum, Blühen und die Samenproduktion von *C. vulgare* gesteigert und (iii) die Ueberlebensrate von *C. vulgare*-Sämlingen erhöht wurden. Es scheint, dass im Entwicklungszyklus von *C. vulgare* der Uebergang vom Sämlings- zum Rosettenstadium die empfindlichste Phase darstellt, in der nur 0,2% in unbeweidetem, resp. 1% in beweidetem Grasland überleben. Die Keimungsrate hingegen beträgt im Mittel 10 und 15% und 49 und 51% der Jungpflanzen im Rosettenstadium entwickeln sich zu adulten Exemplaren. Die Bekämpfung von *C. vulgare* mit Dicamba erwies sich kurz nach Beginn der herbstlichen Regenfälle als am wirksamsten. Dieser Zeitpunkt entspricht einer Periode erhöhter, natürlicher Keimlingsmortalität, bedingt durch eine verstärkte Konkurrenzierung durch benachbarte Pflanzen.

Introduction

Kloot (1983) reported that *Cirsium vulgare* (Savi) Ten. (bull or spear thistle) was one of the first Eurasian thistles to appear in Australia, where it is now one of the most widespread thistles (Parsons, 1973). The species has been declared a 'noxious' weed in New South Wales, Tasmania, Victoria, and Western Australia. In Victoria, it is considered the most important weed of grazed pastures (Shovelton, 1982), and it may be troublesome even in semi-tropical Queensland (George, Hutchinson & Mottershedad, 1970).

Cirsum vulgare is normally biennial. After the seeds are shed in late summer and autumn, they typically germinate with the first substantial rain. By spring the plants have formed small rosettes, which continue to grow under favourable conditions throughout the year. In late spring of the second year, the rosettes begin to bolt, sending up 1–2 m stems which bear 10–200 flowering heads by mid-summer. Densities of only one adult plant m^{-2} were found by Hartley (1983) to reduce spring/summer liveweight gain of sheep by an average of about 2 kg per animal. Stands of mature *C. vulgare* may be so dense as to be impenetrable by livestock or humans, and even after the plants have died, their spiny stems may remain standing, obstructing animal movement, and lowering wool quality for one to two additional years.

Cirsium vulgare is thought to proliferate with grazing and soil nitrogen enrichment (Doing, Biddiscombe & Knedlans, 1966; Michael, 1970). Dense populations of this thistle often occur in heavily grazed pastures, whereas it is rare in ungrazed vegetation. These observations suggest that *C. vulgare* is highly sensitive to interference from other pasture species. Interference may be important throughout the entire life of the plant or at some particular growth stage. In *Carduus nutans* L., for instance, the time necessary to initiate flowering may be doubled by competition from associated pasture plants during the seedling stage (Edmonds & Popay, 1983). Comparison of the life-histories of *C. vulgare* plants in matching grazed and ungrazed pastures would be expected to reveal any such sensitive periods and to provide information on which to base strategies for effective control of this and possibly other thistle species. The need for such information can be seen by the wide variety and disparity of dates of herbicide application that have been found to provide various degrees of control of biennial thistles (cf. Feldman, McCarty & Scrifes, 1968; Young & Evans, 1969; Medd, 1979; Popay & Thompson, 1979; Hurrell, Bourdot & Butler, 1983). To satisfy this need, a 3-year field and laboratory examination of the demography, competitive ability, and chemical control of *C. vulgare* was undertaken. The results are used in an attempt to explain the differential success of *C. vulgare* in grazed and ungrazed pastures and suggest appropriate methods for control.

Methods

Field demography

In 1981 an annual pasture infested with *C. vulgare*, and containing *Bromus rubens* L., *Lolium rigidum* Gaud., *Trifolium subterraneum* L., and *Vulpia* spp. was located at the Ginninderra Experiment Station, Canberra, A.C.T. The pasture had been ploughed and sown with oats (*Avena sativa* L.) in 1979, and the *C. vulgare* plants presumably grew from achenes disturbed by ploughing. Between the oat harvest and August 1981 the pasture was grazed intermittently by sheep. Two portions of the pasture with comparable thistle populations (Table 1) were partitioned with a sheep-proof fence. One portion (1 ha) was left ungrazed for the next 3 years; the

Table 1 (a) Some characteristics of individuals and populations of *C. vulgare* over a period of four years from grazed and ungrazed pastures. (b) Life-stage transition proportions derived from Table 1a

(a) Growing season	Densities† (m^{-2}) of Seeds	Seedlings	Rosettes	Adults	Dry weight (g per plant)	Heads per adult	Seeds per head
			(*Grazed pasture*)				
1980–81	—	276	1·85	0·72	—	44	—
1981–82	8766	396	2·31	1·50	43*	34*	247*
1982–83	1480	570	7·70*	0·10	50*	30*	143*
1983–84	26371*	456*	0·35*	5·25*	73	34*	204*
			(*Ungrazed pasture*)				
1980–81	—	508	2·47	0·64	—	56	—
1981–82	8849	449	2·47	2·00	24	19	178
1982–83	1694	387	0·60	1·10*	15	19	104
1983–84	1833	26	0·07	0·13	48	19	166

(b) Growing season	Seeds to seedlings	Seedlings to rosettes	Rosettes to adults
	(*Grazed pasture*)		
1981–82	—	0·0084	0·8108
1982–83	0·0452	0·0194	0·0433
1983–84	0·3851	0·0006	0·6818
1984–85	0·0174	—	—
Mean	0·149	0·010	0·512
	(*Ungrazed pasture*)		
1981–82	—	0·0049	0·8097
1982–83	0·0507	0·0013	0·4453
1983–84	0·2285	0·0002	0·2167
1984–85	0·0142	—	—
Mean	0·098	0·002	0·491

* Values for a pasture differ significantly ($P < 0·05$) from corresponding values for other pasture.

† Densities are those measured in April or May for seedlings, rosettes, and adults, which are the maximum values observed. Seed densities are cumulative sums from counts made throughout the summer and autumn.

other (0·5 ha) was stocked with five sheep whenever forage was available for grazing.

In both pastures, three 10 × 10 m plots were marked. In 1981, *C. vulgare* seedlings were mapped in five permanent 25 × 25 cm quadrats within each plot, and rosettes were mapped in five permanent 2 × 2 m quadrats. In 1982 and 1983 seedlings were mapped in nine permanent quadrats and 100 rosettes in each pasture were tagged. The fates of mapped and tagged individuals were followed at monthly intervals. Maximum densities of rosettes and adults were determined by counting all plants in the 100-m^2 plots (see above) in April or May of each year.

In January, at the start of flowering, nine sticky traps (Petri dishes spread with a long-lasting adhesive) were placed in each plot. Achenes (hereafter referred to as seeds) of *C. vulgare* within these traps were counted and removed at weekly intervals throughout the seasons of seed dispersal for 1982–'84.

Twenty plants within each pasture were chosen at random, the flowering heads were counted on each plant and at senescence total shoot dry weights were determined. Immediately prior to seed shedding, the fruiting heads were collected and the numbers of viable seeds counted.

Seedling competition experiments

In a series of glasshouse experiments, *C. vulgare* seedlings were grown in competition with seedlings of *L. rigidum* (annual ryegrass) or *T. subterraneum* (subclover), both major components of the vegetation in the field experiments.

Two seeds each of *C. vulgare* and *L. rigidum*, were sown in 40 10-cm diameter pots filled with a 4:1 mixture of sand and vermiculite. *C. vulgare* was sown similarly with *T. subterraneum* in a second group of pots. After seedling establishment the pots were sorted randomly into sub-groups of ten. Sub-groups received one of the following treatments: (i) weekly clipping of the competing plants' leaves and stems to 2 cm above ground level for 10 weeks, (ii) as above for 5 weeks and no clipping thereafter, (iii) no clipping

for 5 weeks followed by weekly clipping for the next 5 weeks, and (iv) no clipping. A further 40 pots were each sown with four seeds of *C. vulgare* alone. All pots received twice-weekly applications of a nutrient solution (1 g $CaPO_4$, 0·5 g $MgSO_4$, 0·55 g KNO_3, 0·8 g $NaNO_3$ and 0·04 g Fe-EDTA l^{-1}). For half of the pots in each group, additional nitrogen (0·2 g NH_4NO_3 l^{-1}) was supplied. Plants were maintained in an unheated glasshouse (day/night temperatures 20°–28°/5°–12°C) and rotated randomly each week. At the final harvest the above and below ground parts of plants were dried and weighed, and analyses of variance performed to compare the dry weights of the groups.

Timing of chemical control

A field experiment was conducted to ascertain whether populations of *C. vulgare* are more sensitive to herbicides when they have low probabilities of 'natural' death or whether they are more sensitive when naturally stressed.

A portion of the grazed pasture was divided into 24 plots, each 5 × 5 m. Sets of five of these plots were sprayed once with 200 g ai ha^{-1} of dicamba on one of the following dates: 31 March, 30 June and 30 September 1983, and 3 January 1984. One set of plots was not sprayed. Treatments were arranged in a Latin-square design. Prior to each spraying, the total number of rosette and/or adult plants of *C. vulgare* was counted in the appropriate plots. Seedlings were also counted in five 15 × 30 cm quadrats within each plot. On 16 February 1984, the numbers of seedlings, rosettes, and adults were counted in all plots. Additionally, as fruiting heads matured, they were collected, air-dried, threshed and their seeds counted to assess effects of seasonal control on seed production.

Results

Annual demography

Initial densities of seedling, rosette, and adult thistles, as well as adult plant size did not differ significantly between the two areas of pasture (Table 1a). However, significant differences quickly arose and by the end of the first year, thistles in the grazed pasture weighed more, and produced more heads and more seeds per head than those in the ungrazed pasture (Table 1a). These differences persisted and were consistent throughout the study period. Significant population differences did not occur until 1982–'83 when rosette numbers in the grazed pasture greatly exceeded those in the ungrazed pasture. Numbers of adult thistles, however, were reduced appreciably because of trampling and grazing during the rosette stage due to the severe drought conditions during 1982–'83. By the 1983–'84 growing season the density of nearly all thistles at all stages in the grazed pasture was considerably higher than that in the ungrazed pasture (Table 1a)..

A life-stage transition matrix can be estimated broadly for *C. vulgare* by dividing the numbers of individuals existing at one life stage in one year by those at the preceding life stage in the previous year (Table 1b). Transition from one life stage to the next is most precarious for seedlings forming into rosettes; average percentages of survival in the grazed compared with the ungrazed pasture were 1·0 and 0·2 respectively. In contrast, relatively high percentages of the large number of seeds produced annually established as seedlings (15% and 10% on average in the two pastures) and approximately half of all rosettes matured into adults in both pastures.

Seasonal demography

The times of the year when rosettes died varied as shown in Fig. 1. In the 1983–'84 growing season most pasture plants made lush growth after the March rains. In the grazed pasture this had little effect on survival of rosettes, but many rosettes died in the ungrazed pasture. The survivors maintained themselves through the remainder of the year to become adults and flower during the 1984 summer. After the March rains in 1982–'83, however, there was little precipitation for the remainder of the year. The soils began drying in late autumn and by early winter there was little pasture growth. The thistles were the only obviously green plants and those in the grazed pasture were being grazed and heavily trampled. A high death rate continued until the stock were removed in October 1982. In the ungrazed pasture the mortality rate was low throughout the winter, but rose markedly in spring. The first year of the study, 1981–'82, was typical in that following the opening March (autumn) rains the winter

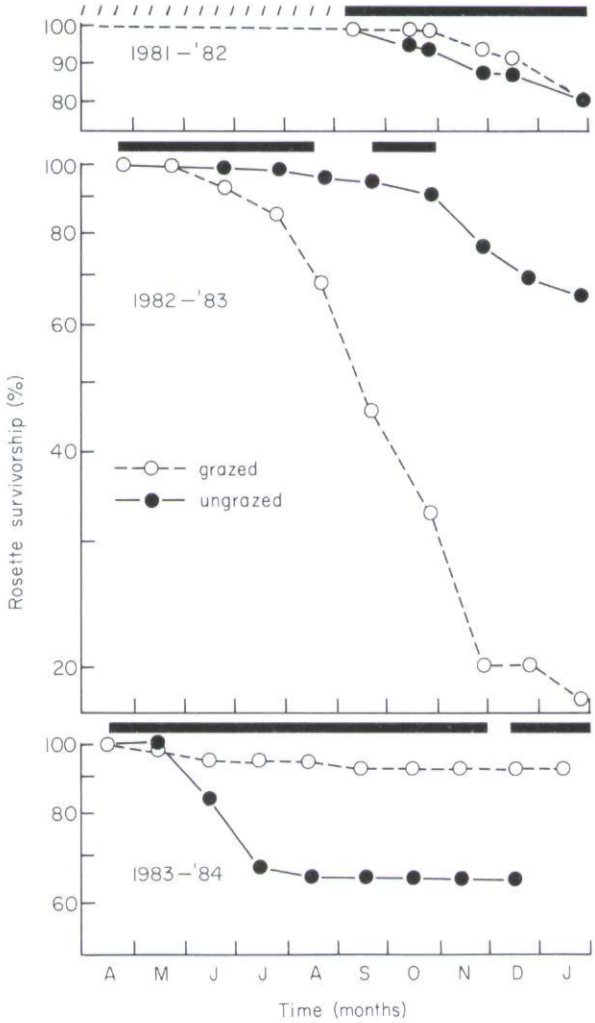

Fig. 1 Seasonal survival of *C. vulgare* rosettes. Solid bars indicate presence of sheep in grazed pasture.

was continuously wet, spring had sporadic rain and the summer was dry. In this case, deaths increased in spring, possibly because of competition from other pasture species under conditions of decreasing soil moisture.

Regardless of when most rosettes died, the survivors in the grazed pasture consistently grew larger and produced more flowering heads and seeds than plants in the ungrazed pasture (Table 1a). The degree of difference between the two was influenced by weather patterns. For instance, the dry weights of senescent grazed pasture plants were greater than those of ungrazed pasture plants by factors of 1·8, 3·3 and 1·5 in 1981–'82 (normal rainfall), 1982–'83 (dry) and 1983–'84 (wet) growing seasons respectively (Fig. 2). However, only the first two differences were significant statistically (Table 1a).

Seedling numbers fluctuated more than rosettes. Seedling survival varied from 27% in the wet year 1983–'84 to 0·1% in 1981–'82 and 1982–'83. Survival of seedlings was generally higher in grazed than ungrazed pasture despite the effects of sheep. Significantly higher death rates were recorded first in autumn and the differences between pastures subsequently increased. From autumn to early spring seedlings in both pastures died at approximately a log-linear rate (Fig. 3a, b

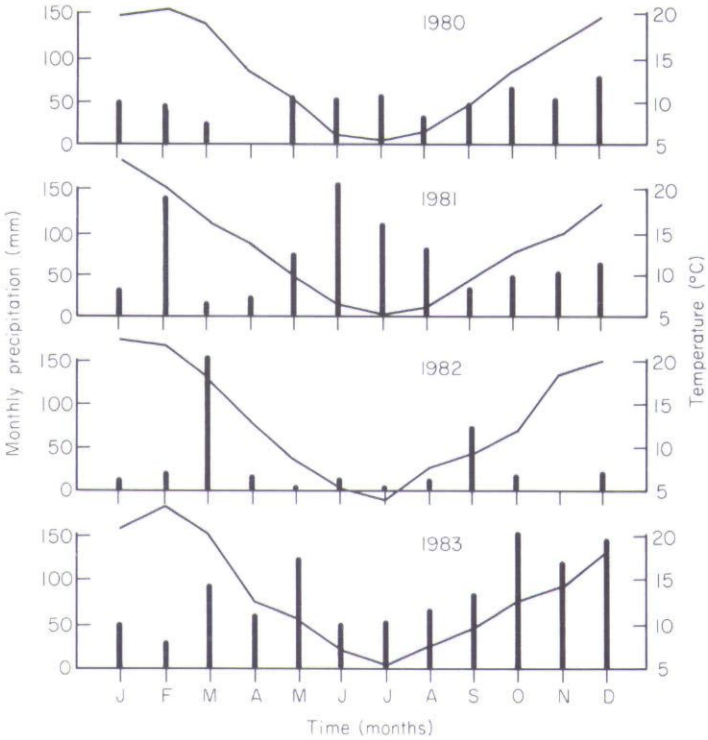

Fig. 2 Temperature and precipitation (bars) for Ginninderra Experiment Station weather station, about 2 km from the experiment site.

and c). During the spring flush of growth the death rate increased noticeably. The increase occurred in early spring in the drought year of 1982–'83, and late spring in the other years.

Seedling competition experiments

Dry weights of *C. vulgare* were affected significantly ($P<0{\cdot}05$) by the species of competing plant, clipping treatment and nitrogen supply (Table 2). In association with *L. rigidum* clipped for the first 5 weeks or for 10 weeks dry weights were high. In contrast, significantly lower weights resulted where the grass was not clipped or clipped only for the last 5 weeks. In association with *T. subterraneum* the growth of *C. vulgare* seedlings increased in all the clipping treatments (Table 2). Addition of nitrogen significantly increased the dry weights of *C. vulgare* in association with *T. subterraneum* clipped for the first 5 or 10 weeks. Without clipping or with clipping in weeks six to ten there was no significant response to nitrogen.

Timing of chemical control

The number of rosettes surviving to adulthood in 1984 was reduced to 10–12% if sprayed with dicamba earlier in the summer (3 January 1984) or in the preceding autumn (31 March 1983) (Table 3). Treatment in winter or spring had no significant effect on the number of rosettes growing to maturity. With the exception of the winter application all treatments reduced seed production, but the effect was greatest with the summer and autumn treatments. High survival of seedlings occurred in plots sprayed in winter, spring and summer. Survival of seedlings in plots sprayed in autumn was low and did not differ significantly from that in control plots.

Discussion and conclusions

Competition from neighbouring plants during the rosette–adult transition of *C. vulgare* has critical effects on subsequent dry weight gain, and flower and seed production of adult plants. On an individual plant basis, these effects are apparent within one growing season. However, with respect to population survival, neither the rosette-adult nor seed-seedling transition phases are as

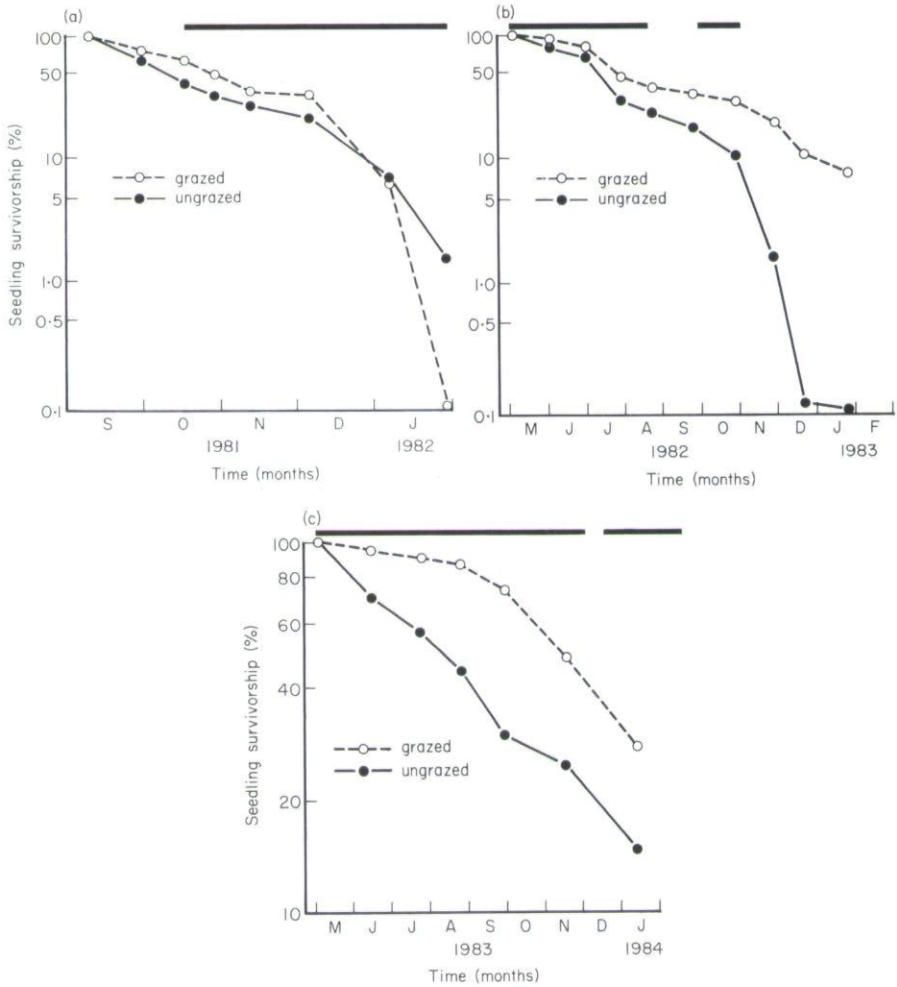

Fig. 3 Seasonal survival of *C. vulgare* seedlings. Solid bars indicate presence of sheep in grazed pasture.

Table 2 Mean dry weights (g) of individual *C. vulgare* plants from glasshouse competition experiment

Nitrogen level	Competing species	Clipping treatment: Throughout	First 5 weeks	Last 5 weeks	Not clipped
Low	Ryegrass	$0{\cdot}86^{ab}$	$1{\cdot}05^{c}$	$0{\cdot}59^{a}$	$0{\cdot}71^{ab}$
	Subclover	$1{\cdot}32^{d}$	$1{\cdot}10^{c}$	$1{\cdot}42^{dc}$	$0{\cdot}63^{a}$
	Thistle	—	—	—	$1{\cdot}35^{cd}$
High	Ryegrass	$1{\cdot}04^{c}$	$0{\cdot}98^{bc}$	$0{\cdot}86^{ab}$	$0{\cdot}73^{ab}$
	Subclover	$1{\cdot}68^{e}$	$2{\cdot}51^{f}$	$1{\cdot}66^{e}$	$0{\cdot}70^{ab}$
	Thistle	—	—	—	$1{\cdot}72^{c}$

Values with at least one superscript in common are not significantly ($P < 0{\cdot}05$) different.

critical as the change from seedling to rosette life stages. In ungrazed and grazed pastures, for example, approximately 10 and 15%, respectively, of all seeds produced germinated to become seedlings, about 49 and 51% of rosettes developed into adult plants, but only 0·2 and 1·0% of seedlings formed rosettes.

The inability of seedlings to form rosettes may have several sources, with competition from neighbouring plants playing a primary role. Effects of competition on individual seedlings and seedling populations of thistles are exemplified by (i) dry weight reductions in glasshouse experiments, (ii) enhanced mortality in ungrazed pastures during autumn and/or spring, times that correspond to optimal periods for plant growth in such pastures (Fitzpatrick & Nix, 1970) and (iii) enhanced survival of thistle seedlings in pastures subjected to grazing in autumn (Bendall, 1973).

Simultaneous chemical control of *C. vulgare* seedlings and rosettes in a Mediterranean-like

Table 3 Effect of time of spraying on fate of *C. vulgare* rosettes maturing into adults, seedlings forming into rosettes, and cumulative seed production at end of summer (March 1984)

	Herbicide application date				
	Autumn (31-3-83)	Winter (30-6-83)	Spring (30-9-83)	Summer (3-1-84)	Control
Rosette survival (%)	12^b	84^a	59^a	10^b	81^a
Seedling survival (%)	19^c	87^a	39^b	65^a	25^c
Seed production (no. m^{-2})	668^c	8956^a	3476^b	476^c	8148^a

Values with differing superscripts differ significantly ($P < 0.05$).

environment appears effective only after rain commences in autumn. At other times, the plants may not be growing actively enough to respond to herbicides. Additionally, during winter through to summer large rosettes and adult plants may screen seedlings from contact with herbicide sprays.

In terms of management practice in typical Mediterranean-like annual grass/clover pastures our results suggest that control of *C. vulgare* might best be effected as follows:

(i) Cessation of grazing in autumn, particularly if the pasture is growing rapidly after the start of autumn rains.

(ii) Application of an appropriate herbicide such as dicamba at the same time so as to suppress those plants that have not been affected by competition.

(iii) Promotion of annual ryegrass growth over that of subclover. This may be accomplished by use of a herbicide toxic to both the thistle and clover (e.g. dicamba), or, where possible, ploughing the pasture shallowly (5–10 cm) in May or June (Forcella & Gill, 1985).

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