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Effects of shepherd's purse (*Capsella bursa-pastoris* L. Medic.) on the growth of radish (*Raphanus sativus* L.)

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Summary: Résumé: Zusammenfassung

Radish (*Raphanus sativus* L.), a salad vegetable, and shepherd's purse (*Capsella bursa-pastoris* (L.) Med.), a common annual or biennial weed, are plants of similar height, leaf area and root biomass which often occur together in early summer. To assess the effects of the weed on the crop, plants were grown in well-watered and fertilized monocultures and mixtures in the greenhouse. Growth of both species in monoculture decreased, per plant, as planting density increased, particularly in radish which had a high relative monoculture response. In mixtures, at a range of planting densities, and in different proportions, radish was much the stronger competitor, its total dry matter and tuber production being affected only slightly, and not at all in some experiments, by mixture with *C. bursa-pastoris*. Thus the relative mixture response of radish ranged from 0·1 to 0·0, and the relative crowding coefficient of radish over *Capsella* was high, indicating that radish was strongly aggressive in the mixture. Although the two species had similar leaf areas in monoculture, that of *C. bursa-pastoris* was greatly reduced in mixture. The advantage displayed by radish in intercepting light was further enhanced when it was grown in mixtures because radish increased the height of the greatest part of its leaf area, so increasing its shading of the weed. Withholding water from plants increased dry matter partitioning to the root systems in both species, and slightly increased the competitive advantage of radish over *C. bursa-pastoris*. It is concluded that the weed poses little threat to the yield of radish crops in the field.

*Effets de la capselle bourse a pasteur (*Capsella bursa-pastoris *L. Medic.) sur la croissance du radis (*Raphanus sativus *L.)*

Le radis (*Raphanus sativus* L.) et la capselle bourse à pasteur (*Capsella bursa-pastoris* L. Medic) mauvaise herbe annuelle ou bisanuelle commune, sont des plantes de hauteur, surface foliaire et système racinaire semblables qui apparaissent souvent ensemble au début de l'été. Pour évaluer les effets de l'adventice sur la culture, les plantes ont été cultivées en monoculture et en culture mixte sous serre avec un bon arrosage et une bonne fertilisation. La croissance des deux espèces en monoculture a diminué par plante parallèlement à l'augmentation de la densité, en particulier chez le radis qui a une réponse à la monoculture relativement élevée. En mélanges, sur un éventail de densités de plantation et dans différentes proportions, le radis a été un compétiteur plus fort avec un poids total en matière sèche et une production tubéreuse peu affectée, et pas dans tous les essais, par le mélange avec la capselle. Ainsi, la réponse au mélange du radis a varié de 0,1 à 0,0 et le coefficient de masse relative du radis par rapport à capselle était élevé, soulignant que le radis était fortement compétiteur dans le mélange. Bien que les 2 espèces aient des surfaces foliaires semblables en monoculture celle de *C. bursa-pastoris* a été considérablement amoindri en mélange. L'avantage que le

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radis tire de son interception de la lumière, a été favorisé dans la culture en mélange parce que le radis a accru la hauteur à laquelle se trouvait la majorité de sa surface foliaire, augmentant ainsi son ombrage de l'adventice. En réduisant la source en eau des plantes, on a eu une augmentation de la matière sèche au niveau des racines chez les 2 espèces avec une légère contribution à l'augmentation de l'avantage du radis sur la capselle. Il en est conclu que l'adventice représente une faible menace pour le rendement des cultures de radis au champ.

*Konkurrenz von Hirtentäschel (*Capsella bursa-pastoris *(L.) Medic. mit Radieschen (*Raphanus sativus *L.)*

Die Gemüsepflanze Radieschen (*Raphanus sativus* L.) und das verbreitete, ein- bis überjährige Unkraut Hirtentäschel (*Capsella bursa-pastoris* (L.) Medic.) haben eine ähnliche Höhe, Blattfläche und Wurzelmasse, sie treten im Frühsommer oft zusammen auf. Um die Wirkung des Unkrauts auf die Kulturpflanze zu untersuchen, wurden die Pflanzen im Gewächshaus in gut gewässerten und gedüngten Rein- und Mischbeständen kultiviert. Bei beiden Arten nahm das Wachstum der Einzelpflanze mit zunehmender Dichte ab, besonders beim Radieschen. In Mischbeständen mit verschiedenen Pflanzendichten und Mischungsverhältnissen war das Radieschen der stärkere Konkurrent, dessen Gesamttrockenmasse und Rübchenertrag nur wenig und in manchen Versuchen überhaupt nicht durch das Unkraut beeinträchtigt wurden. So variierte die relative Reaktion des Radieschens in den Mischbeständen (mixture response) von 0,1 bis 0,0, und der relative Verdrängungskoeffizient des Radieschens über *Capsella* war hoch, worin zum Ausdruck kommt, wie konkurrenzstark das Radieschen in den Mischkulturen war. Obwohl die beiden Arten in Reinbeständen ziemlich ähnliche Blattflächen entwickelten, war diese bei *Capsella* in Mischbeständen erheblich reduziert. Das Radieschen erlangte in Mischbeständen auch dadurch einen Vorteil bei der Lichtaufnahme, indem der größte Teil seiner Blattfläche höher lag und so das Unkraut zunehmend beschattete. Bei Wassermangel stieg die Wurzeltrockenmasse bei beiden Arten an, wodurch der Konkurrenzvorteil des Radieschens gegenüber dem Hirteltäschel leicht verstärkt wurde. Diese Unkrautart übt also nur eine kleine Schadwirkung auf den Ertrag von Radieschen aus.

Introduction

Shepherd's purse (*Capsella bursa-pastoris* (L.) Med.) was classified by Holm *et al.* (1977) as one of the world's worst weeds. It is common on cultivated land throughout Europe. Seeds require a cold period to break their dormancy and, although some germination occurs throughout the year, the greatest flushes are in spring (Salisbury, 1964; Popay & Roberts, 1970). Radish (*Raphanus sativus* L.) is a widely cultivated spring vegetable (456 ha were grown in England and Wales in 1985) whose tuberous root or, occasionally, leaves are eaten in salads. The two species may be readily observed growing together and are similar in several respects. The seed-to-seed period of *C. bursa-pastoris* and the seed-to-harvest time of radish are similarly short, of the order of 5–10 weeks, the two species are of similar height, rarely exceeding 30 cm and, as we confirm, they have a similar below-ground biomass. The effects of the weed on the crop have not been published previously and were therefore investigated in this study. The way in which drought might affect interactions between the crop and the weed was examined because both species are relatively shallow rooting and, therefore, might be particularly sensitive to drying of the upper regions of the soil in early summer.

Materials and methods

A pure seed-line of *Capsella bursa-pastoris* was collected locally and stored in the refrigerator. Seeds were sown in trays of Shamrock potting compost (Irish Peat Development Authority). Seed of radish (*Raphanus sativus* L.), cv. French Breakfast, supplied by D. T. Brown, Blackpool, UK, was sown in trays of similar compost. Germination occurred in summer in the greenhouse in which experiments were carried out.

In experiments to investigate the effects of time of planting, density, and species proportions, plants were grown in tubs 17 × 17 × 15 cm deep containing a mixture of two parts top soil (University Field Station) to one part coarse sand. Seedlings of the two species were pricked into their final position in the tubs when the first true leaves were unfolded. Sowing of *C. bursa-pastoris* was staggered for the purposes of the first experiment and, thereafter, was arranged to ensure that each species could be pricked out, i.e. put in mixtures, on the same day. Each treatment was replicated six times. In order to minimize edge effects, leaves were supported by stakes and raffia so that they were held within the area of the tub, the tubs were juxtaposed and the position of individual tubs on the greenhouse bench was regularly re-randomized.

In an experiment to investigate the effects of drought, plants were grown in grids (17 × 17 cm) in the same soil mix but in larger containers, 43 × 43 × 36 cm deep. There were four planting grids in each large container, and the roots of the plants in each grid were separated from those in the other grids by an encircling tube of cotton mesh held on a 17 × 17 × 36 cm deep wire frame. Monocultures of the two species and mixtures were randomly allocated to the grids, thus ensuring that different planting treatments within the same container were at the same soil water potential. Each treatment was replicated six times. Half of the containers were well watered regularly (wet treatment), while water was withheld from the remaining containers (dry treatment) for 7 days after the plants had been pricked out. Soil water potential was measured using an HR 33T dewpoint hygrometer (Wescor Inc., Logan, Utah, USA) with C52 sample chambers. Each chamber was individually calibrated against a range of NaCl solutions. Soil was extracted from different depths using a core borer 1 cm in diameter.

At harvest, the leaf area of fresh material was measured using an automatic planimeter, and radish tuber fresh weights were then measured. Roots were carefully washed under running tap water until all adhering soil was removed and then, with other plant organs, dried for 48 h in a forced draught oven at 80°C before weighing.

The relative crowding coefficient for radish, with respect to *C. bursa-pastoris* (K_{rc}), is a measure of the aggressiveness of one species towards another and was calculated according to De Wit (1960):

$$K_{rc} = \frac{\text{yield of radish in mixture/yield of } C.\ bursa\text{-}pastoris \text{ in mixture}}{\text{yield of radish in monoculture/yield of } C.\ bursa\text{-}pastoris \text{ in monoculture}}$$

Relative monoculture (R_m) and relative mixture (R_x) responses, which are measures of the effects on yield of intra- and interspecific competition, respectively, were calculated according to Joliffe *et al.* (1984).

Results

Time of planting of C. bursa-pastoris

Growth of each radish plant in mixture with *C. bursa-pastoris* (8:8 plants) was greater than that in monoculture (16 plants), although both the total and tuber dry weight of radish were reduced when it was planted among *C. bursa-pastoris* established 8 or 16 days earlier (Table 1). Relative crowding coefficients showed that radish was much the stronger competitor. Since there was little difference whether *C. bursa-pastoris* was planted 8 or 16 days before radish, the former time was used in all subsequent experiments.

Plant density

As planting density increased, both total dry weight per tub (Fig. 1) and leaf area index (LAI = leaf area divided by tub area) (Fig. 2), for both species in monocultures and mixture, increased in all treatments. Radish monocultures and mixtures, and *C. bursa-pastoris* monocultures, approached a plateau at densities above 16 plants per tub, although the total dry weight of *C. bursa-pastoris* in monoculture was significantly less than that of radish monoculture or mixture at each density. However, *C. bursa-pastoris* in a mixture reached a plateau at a density of about 4 plants per tub. Radish tubers in both monocultures and mixtures reached a plateau value of 4·2 g dry weight per tub (equivalent to 90 g fresh weight per tub) at 9 plants per tub (Fig. 1).

The relative monoculture response of radish was >0·5 at all densities above 8 plants per tub, while the relative mixture response was <0·1 at all densities (Fig. 3a,b). The relative monoculture response of *C. bursa-pastoris* exceeded 0·5 only at densities greater than 16 plants per tub, and its relative mixture response exceeded 0·5 at

Table 1. Effect of time of planting of *Capsella bursa-pastoris* on total dry weight and tuber dry weight of radish, and relative crowing coefficient (K_{rc})

Capsella planted before radish (days)	Total dry weight (g^{-1} plant)		Tuber dry weight (g^{-1} plant)		
	Monoculture	Mixture	Monoculture	Mixture	K_{rc}
0	0·47 ± 0·07	0·79 ± 0·10	0·20 ± 0·03	0·40 ± 0·06	10·3 ± 1·6
8	—	0·58 ± 0·05	—	0·30 ± 0·04	5·4 ± 1·7
16	—	0·63 ± 0·07	—	0·34 ± 0·04	4·4 ± 1·0

Each value is the mean of six replicates with standard error.

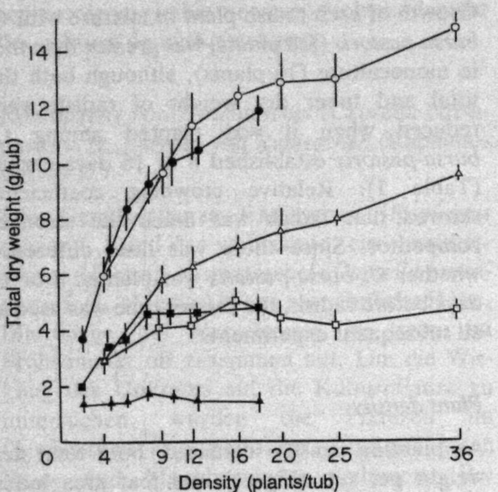

Fig. 1. Total dry weight of radish monoculture (○) and *Capsella* monoculture (△), and 1:1 mixture (●, ▲), at a range of planting densities. Dry weight of radish tubers in monoculture (□) and mixture (■). Bar indicates the standard error of the mean for six replicates.

all densities above 4 plants per tub. Thus, with increasing plant density, radish responded almost exclusively to radish, i.e. to intra-specific competition, while *C. bursa-pastoris* also responded mainly to radish, i.e. to interspecific competition.

Species proportions

The effects of varying the proportions of the species were examined at a density of 16 plants per tub, i.e. in the range where the two species in monoculture had similar LAIs (data not shown, but similar to those in Fig. 2) in the previous experiment. Replacement series experiments showed that shoot and root growth in monoculture (16) was similar, but again radish was the stronger competitor in mixtures, the curves for shoot, root and tuber of radish being strongly convex, while those for *C. bursa-pastoris* were concave (Fig. 4).

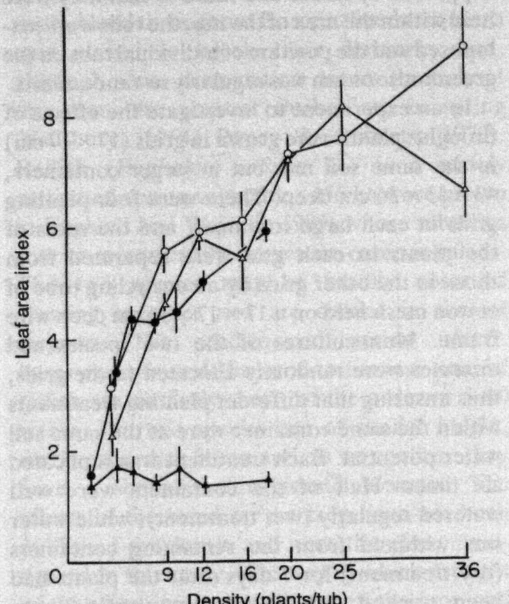

Fig. 2. Leaf area index of radish monoculture (○) and *Capsella* monoculture (△), and 1:1 mixture (●, ▲), at a range of planting densities. Bar indicates the standard error of the mean for six replicates.

Total LAIs in monoculture were again similar for the two species (5·9 ± 0·4 for radish and 5·4 ± 0·3 for *C. bursa-pastoris*). For both species, the largest component of the total was in the zone 7–14 cm high (Fig. 5). In mixture, the total LAI of radish was 4·2 ± 0·2 and that of *C. bursa-pastoris* was 1·3 ± 0·2. Moreover, while the largest component for radish was 14–21 cm high, and a significant component was 21–28 cm high, the largest component for *C. bursa-pastoris* was again only 7–14 cm high.

Dry soil

Soil water potential decreased with time in all dry treatments, but at any time it increased with increasing depth (Fig. 6). In both wet and dry soil, mixture with *C. bursa-pastoris* reduced the

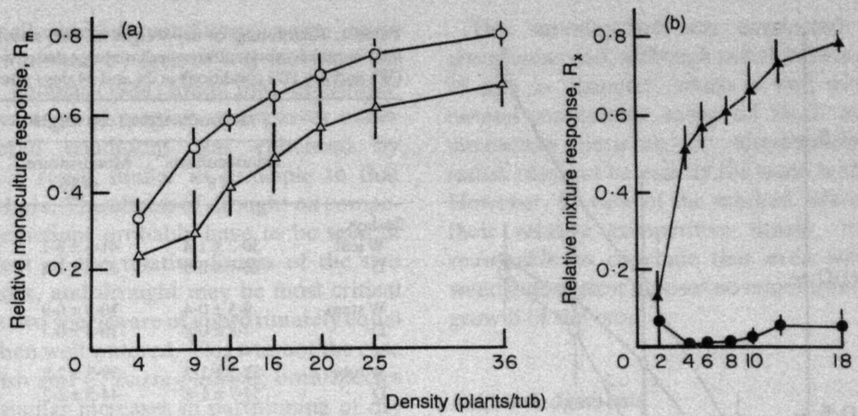

Fig. 3. (a) Relative monoculture response of radish (○) and *Capsella* (△), and (b) relative mixture response of radish (●) and *Capsella* (▲) at different planting densities. Bar indicates the standard error of the mean for six replicates.

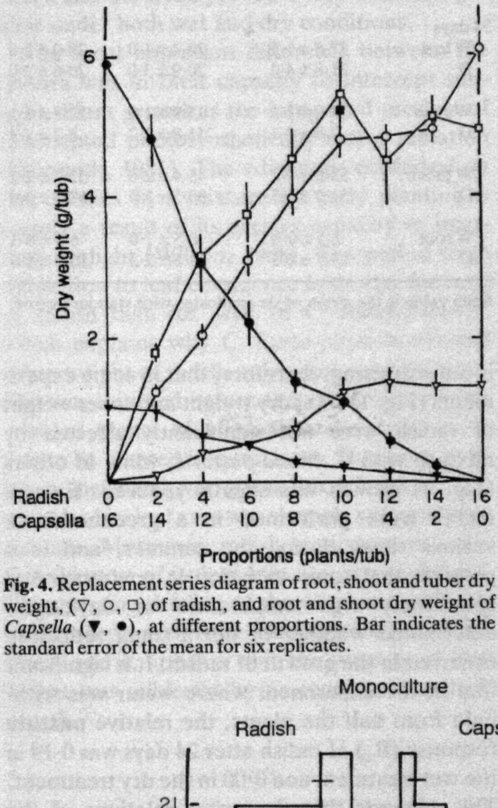

Fig. 4. Replacement series diagram of root, shoot and tuber dry weight, (▽, ○, □) of radish, and root and shoot dry weight of *Capsella* (▼, ●), at different proportions. Bar indicates the standard error of the mean for six replicates.

total plant dry weight of each radish compared with that in monoculture of 8, although the dry weight of radish in mixture was greater than that in monoculture of 16 (Fig. 7). These relative effects were not altered by dry soil, although growth was inhibited in each planting treatment.

C. bursa-pastoris did not affect the partitioning of dry weight of radish in mixture when compared with monocultures of 8, although monocultures of 16 radish partitioned more dry weight to leaves and less to tubers than either radish in mixture or monocultures of 8, particularly 24 days after planting (Table 2). In each planting treatment, radish in dry soil tended to partition less dry weight to leaf and stem and more to root and tuber than in wet soil.

Discussion

This is the first report of the effects of *C. bursa-pastoris* on the growth and yield of radish.

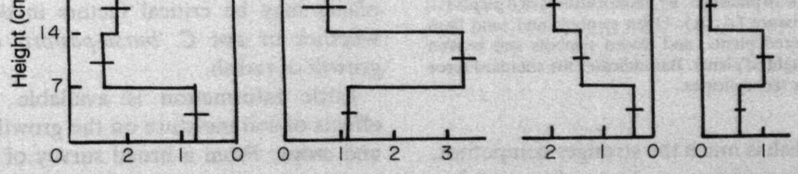

Fig. 5. Histogram of leaf area index at bands 0–7 cm, 7–14 cm and >21 cm above soil level in monocultures and mixture of radish and *Capsella*. Bar indicates the standard error of the mean for six replicates.

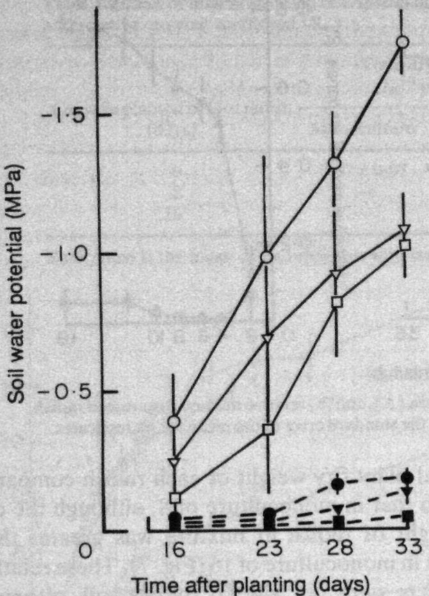

Fig. 6. Soil water potential in the top (0–12 cm; ○, ●), middle (12–24 cm; ▽, ▼) and bottom (24–36 cm; (□, ■) regions of soil columns. Open symbols show dry soil; closed symbols show well-watered soil. Bar indicates the standard error of the mean for six replicates.

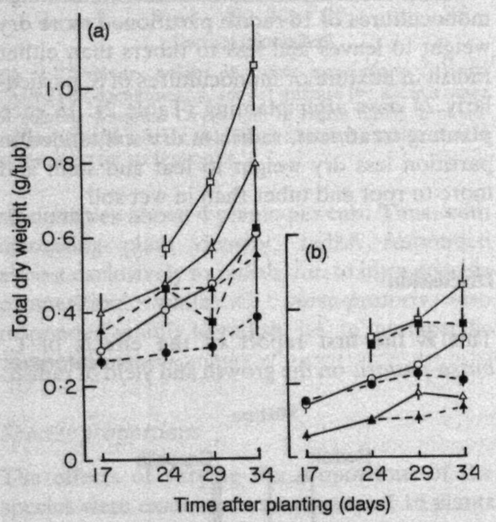

Fig. 7. Total dry weight per plant of (a) radish and (b) *Capsella* monocultures of 16 plants (○, ●), monocultures of 8 plants (□, ■), and 1:1 mixture (△, ▲). Open symbols and solid lines show well-watered plants, and closed symbols and broken lines show droughted plants. Bar indicates the standard error of the mean for six replicates.

Clearly, radish is much the stronger competitor, with a relative mixture response close to 0·1 at all planting densities (Fig. 3b) (also, at all proportions with the weed; data not shown). It

Table 2. Partitioning of dry weight to leaf, stem, tuber and root in radish monocultures and mixtures under well-watered (W) and dry (D) conditions at 24 and 34 days after planting.

	Fraction % of total dry weight		
	Monoculture of 8	Monoculture of 16	Mixture
24 days			
W leaf	30·2 ± 1·4	41·5 ± 4·1	33·2 ± 4·1
D	26·7 ± 0·9	30·5 ± 1·2	27·8 ± 1·4
W stem	9·5 ± 0·4	10·5 ± 0·9	8·6 ± 0·4
D	7·8 ± 0·8	10·8 ± 0·7	8·0 ± 0·4
W tuber	52·3 ± 1·7	39·3 ± 2·8	50·2 ± 3·9
D	54·7 ± 1·8	44·5 ± 2·2	54·1 ± 1·6
W root	8·0 ± 1·3	8·7 ± 0·8	8·0 ± 0·6
D	10·8 ± 0·5	14·2 ± 2·2	10·1 ± 1·3
34 days			
W leaf	27·8 ± 1·5	28·4 ± 1·0	28·0 ± 2·0
D	21·8 ± 4·0	20·9 ± 3·0	20·6 ± 2·0
W stem	11·0 ± 1·1	15·9 ± 1·0	12·8 ± 1·1
D	7·0 ± 0·1	11·8 ± 1·7	8·2 ± 1·4
W tuber	53·6 ± 4·2	45·4 ± 2·6	52·7 ± 2·2
D	54·0 ± 5·5	50·5 ± 3·9	57·5 ± 3·0
W root	6·5 ± 0·8	8·5 ± 1·0	6·5 ± 0·3
D	13·7 ± 4·3	14·5 ± 2·2	10·9 ± 1·6

Each value is the mean of six replicates with standard error.

is not surprising, therefore, that in some experiments (Fig. 1) total dry weight and tuber weight of radish were not significantly affected by mixture with *C. bursa-pastoris*, while in others (Fig. 7) growth was slightly reduced. Experiments were performed in a greenhouse at various times during the summer, and it is possible that some variation in environmental conditions, e.g. temperature or daylength, determined whether or not a small reduction occurred in the growth of radish. It is significant that in the experiment where water was withheld from half the plants, the relative mixture response (R_x) of radish after 24 days was 0·19 in the wet treatment and 0·00 in the dry treatment. This suggests that the water relations of the plants may be critical factors in determining whether or not *C. bursa-pastoris* affects the growth of radish.

Little information is available about the effects of soil moisture on the growth of weeds and crops. From a broad survey of 10 species growing in one complex mixture (some weeds, some crops), Wiese & Vandiver (1970) concluded that the species that grew most strongly under well-watered conditions were most severely inhibited by lack of soil moisture. In contrast, Thomas (1984) found that the competitive advantage of ryegrass over clover under well-watered conditions was enhanced by drought, a result similar in principle to that reported here. The effects of drought on competitive interactions probably have to be seen in the context of the relative fitness of the two competitors, and drought may be most critical when the two species are of approximately equal fitness when well watered. This was not the case with radish and *C. bursa-pastoris*; both species showed similar increases in partitioning of dry matter into the root system under dry conditions, and the weed proved a very weak competitor under both wet and dry conditions.

The most important difference between the species was in their capacity to intercept sunlight. Plant growth is the integrated product of intercepted photosynthetically active radiation (Monteith, 1981). The advantage conferred on one species in a mixture by early planting is largely a result of its greater capacity to intercept sunlight (Wilson, 1988). The period from imbibition to leaf emergence is shorter for seed of radish than for seed of *C. bursa-pastoris*, which explains why *C. bursa-pastoris* affected tuber weight of radish only when seed germination was initiated before that of radish, for this enabled plants of approximately equal shoot size to be planted into mixtures. However, even when the weed was given this advantage, the growth of its leaf area was strongly suppressed in mixture. Moreover, radish in mixture was able to hold most of its leaf area at a greater height, so increasing shading of the weed and reducing its interception of light. Radish has a very short stem, and it appears that the increase in leaf height was achieved by an increase in petiole length.

This investigation was conducted in the greenhouse and, although radish tubers grew to 25 mm in diameter, which is well within the normal marketable range of 18–32 mm, the interaction between *C. bursa-pastoris* and radish may not be exactly the same in the field. However, in view of the marked diferences in their relative competitive fitness, it seems reasonable to conclude that even where the weed is abundant is poses no major threat to the growth of the crop.

Acknowledgements

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