Regeneration of yarrow (*Achillea millefolium* L.) rhizomes as influenced by rhizome age, fragmentation and depth of soil burial

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Summary

Fragmentation of rhizomes from mature plants of the perennial weed, yarrow (*Achillea millefolium* L.) lead to the rapid release of rhizome buds from apical dominance. Stimulation of bud activity was dependent upon the age and length of rhizome fragments, with the middle age class (1 year old) shorter (30 mm) fragments showing the greatest bud activity after 14 days of soil burial. The pattern for shoot emergence (after 80 days) was similar, although longer fragments (90 mm) were more likely to produce aerial shoots from activated buds, particularly after burial at 100 mm. No shoot emergence occurred from 200 mm, although initial bud activity was *c.* 30%. Fragmentation of the two younger rhizome classes (0.5–1 year old) into short pieces (30 mm) lead either to emergence of shoots or rotting of the rhizome with few dormant buds remaining in the soil. Fragmentation of older rhizomes (> 1 year old) or fragmentation into 90-mm pieces resulted in up to 31% of buds remaining dormant. The results are discussed in relation to the use of single or multiple cultivations for the control of rhizomatous yarrow plants.

Introduction

Yarrow (*Achillea millefolium* L.) is a rhizomatous, perennial herb which has become a major problem in some arable crops grown in Canterbury and Otago, New Zealand (Bourdôt *et al.* 1979). While Warwick and Black (1982) reviewed the biology of yarrow, emphasizing reproduction by seed and rhizomes, they did not provide information on the regeneration of plants from fragmented rhizomes following cultivation of arable land.

Bud dormancy is a common phenomenon in many rhizomatous, perennial weeds, including couch (*Elytrigia repens* (L.) Beauv.) (syn. *Agropyron repens* (L.) Beauv.) (Johnson and Buchholz 1962); Johnsongrass (*Sorghum halapense* L.) (Hull 1970) and yarrow (*Achillea millefolium* L.) (Bourdôt *et al.* 1979). The characteristic of strong apical dominance in rhizomes leads to extensive lateral spread of plants and rapid vegetative propagule formation on fragmentation by cultivation (Bourdôt *et al.* 1982). The ability of rhizome fragments to establish new individual plants is influenced largely by the relationship between the mass and availability of stored reserves, the number of developing buds and the depth of burial in the soil. The commencement of autonomous growth and full photosynthetic function can then readily lead to plant establishment (Bourdôt *et al.* 1982). The reimposition of apical dominance in rhizome fragments and the ease of establishment of new plants from fragments have emphasized the need for multiple cultivations in the cultural control of rhizomatous weeds that may be wholly or partially resistant to herbicides (Fail 1956; Bourdôt and Butler 1985). The present study has investigated a number of factors — rhizome age, fragment length and depth of burial in soil — that may influence new plant establishment following cultivation of established plants.

Materials and methods

The experiment was carried out at Lincoln College on a Wakanui silt loam soil. Yarrow rhizomes were collected from natural populations growing at similar sites on 9 February 1983. Rhizomes were divided into three age classes according to the following schedule:

Class	Diam. range (mm)	% dry wt	Age (months)
1	2.0–2.5	23	< 6
2	2.5–3.0	28	6 –12
3	3.5–5.0	32	> 12

Determination of age was based on colour, physical characteristics and experience from handling the material.

Rhizomes were cut into 30, 60 or 90-mm fragments that had 1.2, 2.5 or 5.0 buds respectively and were placed at 5°C in moist cheesecloth until planting. Rhizomes were buried in soil by excavation of trenches (200 mm × 500 mm). The trenches were excavated to depths of 25, 50, 100 or 200 mm. Ten fragments, which constituted one replicate, were placed 30 mm apart in each trench and covered with compacted soil. The trenches were arranged in rows in a randomized block design of three age classes, three fragment lengths and four depths of burial with five replicates. Soil was maintained at field capacity by overhead irrigation and weeds were removed by hand.

Plant material was removed on two occasions in order to establish bud activity (shoots > 20 mm in length) after 14 days and shoot emergence after 80 days. On each occasion five rhizome fragments were carefully retrieved and the following parameters determined: length of each bud/shoot, percentage of fragment length that was rotted, the mean dry weight of an emerged shoot. Bud activity and shoot emergence were expressed as a percentage of the number of buds planted.

Results

The mid-aged (class 2) rhizomes had the highest percentage bud activity, irrespective of planting depth (Figure 1*a*) or fragment length (Figure 1*c*). The youngest (class 1) rhizomes had consistently the lowest values for bud activity, while the oldest rhizomes (class 3) were intermediate. Bud activity was lower at greater planting depths, (Figures 1*a* and *b*) and with increased fragment length (Figures 1*b* and *c*).

Shoot emergence essentially followed the pattern of bud activation in the interaction between rhizome age and depth of burial, although it was always lower, and no emergence occurred at 200 mm, (Figure 1*a*). The major influence on shoot emergence was fragment length. The high bud activity of 30-mm fragments, irrespective of planting depth, was followed by a highly significant reduction in shoot emergence, particularly at a depth of 100 mm (Figure 1*b*). A similar but less dramatic change was noted for 60-mm fragments, while values for shoot emergence from 90-mm fragments were greater than for bud activity, particularly at 100 mm depth (Figure 1*b*). There was consistently greater bud activation than shoot emergence with 30-mm fragments, while the reverse relationship was found for 90-mm fragments, irrespective of rhizome age (Figure 1*c*).

The rotting of portions or entire fragments was associated with shoot emergence. Rhizome rotting decreased

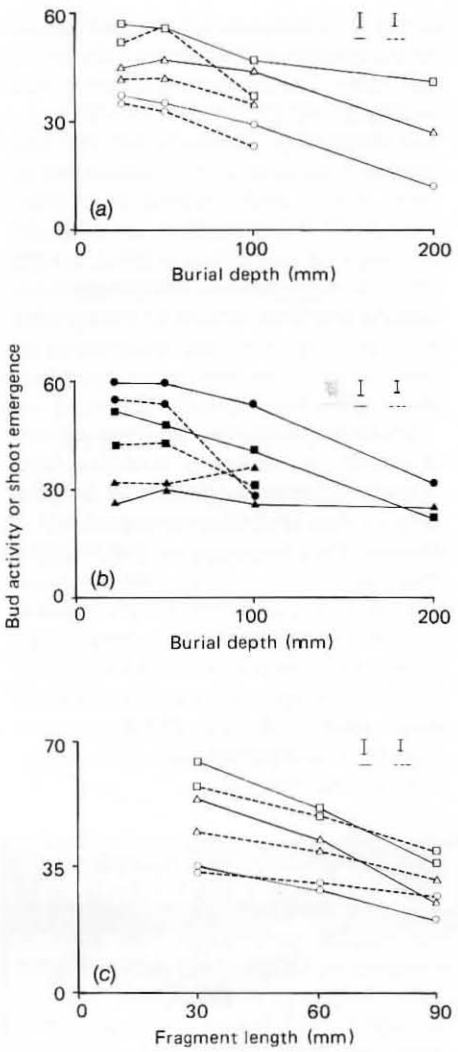

Figure 1 The interactions of (a) rhizome age (class 1, ◎; class 2, □; class 3, Δ) with burial depth, (b) fragment length (30 mm ●; 60 mm ■; 90 mm ▲) with burial depth and (c) rhizome age with fragment length on bud activity (—) and shoot emergence (----). Vertical bars indicate one standard error of the mean ($P \leqslant 0.05$).

with increasing age and fragment length but increased with depth of burial, such that all rhizomes decayed at 200 mm (Table 1). Addition of data for rhizome rotting and percentage bud emergence reveals the percentage of dormant buds remaining in the soil (Table 1). The minimum number of dormant buds was associated with class 2 rhizomes cut into short (30 or 60-mm) fragments, while the maximum involved class 3 rhizomes of 90 mm in length. Depth of fragment burial had no major effect on the number of dormant buds after 80 days of burial. There was an increase in weight of emerged shoots as fragment length increased. However, the most significant influences on shoot weight were major reductions associated with burial at 100 mm or rhizome-age class 1, (Table 1).

Table 1 The effect of rhizome age, planting depth and fragment length on rhizome rotting, bud emergence and mean weight of emerged shoots (main effects only presented)

	Rhizome rotting (%)	Bud emergence (%)	Mean weight per shoot (mg)
Rhizome age class			
1	50	30	87
2	41	48	190
3	36	40	163
Planting depth (mm)			
25	38	43	196
50	42	43	179
100	48	31	64
200	100	–	–
Fragment length (mm)			
30	49	45	129
60	43	40	147
90	36	33	164
s.e. ($P \leqslant 0.05$)	0.6	0.5	2.8

Discussion

The fate of buried rhizome fragments is a crucial factor in the control of yarrow in arable situations (Bourdôt *et al.* 1979). The rapid re-imposition of apical dominance after fragmentation almost certainly accounted for the greater bud activity after 14 days as fragment length decreased (Figure 1*c*) and confirms earlier findings (Bourdôt *et al.* 1982; Bourdôt 1984). The results shown in Figure 1*c* suggested that some bud activity was delayed because of higher final shoot-emergence figures for 90-mm fragments. The lack of correspondence between bud activity and subsequent shoot emergence on single rhizome-fragments may contribute to difficulties in controlling yarrow by multiple cultivations (Bourdôt *et al.* 1982).

The number of emerged shoots as a proportion of total buds available decreased with increasing fragment length, confirming that strong apical dominance was suppressing viable buds in multi-node fragments (Figure 1*b*) (Bourdôt *et al.* 1982). The suppression of buds on longer fragments and the reduced rotting (Table 1) would make more resources available for shoot growth. This was reflected in the higher shoot dry weight (Table 1), although no account was taken of any contribution by current photosynthesis.

Effects of rhizome age have not previously been established but were very significant, as measured by bud activity and shoot emergence (Figures 1*a* and *c*). The class 2 rhizomes that were *c.* 1 year old were consistently the most viable and active. There would appear to be some advantage in controlling the younger class 1 rhizomes which had a lower regenerative ability but higher percentage rotting and hence fewer dormant buds in the soil. The reduced bud emergence, particularly after deeper soil burial, was probably related to the reduced availability of stored reserves which, per unit length of rhizome, were up to 73% lower than for class 3 rhizomes because of reduced diameter and percentage dry weight (see Materials and methods). The significantly greater rotting of class 1 rhizomes, plus the major reduction in mean shoot dry weight (Table 1), provide further evidence that newly formed rhizomes were not sufficiently mature to produce totally effective vegetative propagules following fragmentation. In contrast, the class 2 rhizomes produced a similar number of emerged shoots after burial at 100 mm as class 3 rhizomes (Figure 1*a*) and shoots of similar weights (Table 1). The results confirm that cultivation of yarrow plants that have young, developing rhizomes is likely to give more effective control than the cultivation of plants that have been established for 1 year or more (Bourdôt *et al.* 1982; Bourdôt and Butler 1985).

The lack of shoot emergence from a depth of 200 mm despite significant bud activity (Figures 1*a* and *b*) was anticipated for 30- and 60-mm fragments (Bourdôt 1984) but some emergence from 90-mm fragments could have been expected. Deep burial of short fragments is an obvious, but not entirely practical, method of eliminating rhizomes. However, longer fragments (160 mm) may produce shoots from 250–300 mm (Bourdôt 1984). Virtually all the evidence suggests that the availability of stored reserves limits shoot growth, although the reduced bud activity with increasing burial depth suggests that environmental factors are influential. Unlike seed burial, where reduced temperature and high levels of carbon dioxide may improve dormancy (Taylorson 1970), there was no long-term survival of buried rhizomes when buds had not been activated within 14 days.

The use of cultivation as a means of controlling yarrow is partially effective (Bourdôt and Butler 1985). The present data confirm that rigorous cultivation of rhizomes into short fragments is necessary for maximum bud activity, with surface dessication (Bourdôt *et al.* 1982) or deep burial being desirable. Young rhizomes (classes 1 and 2), including new ones produced after fragmentation, would be easiest to eliminate by cultivation. In the absence of effective herbicides (Field and Jayaweera 1985) and irrespective of rhizome age, fragment length or depth of burial, at least two cultivations would probably be needed in order to eliminate all rhizome buds.

Acknowledgments

The New Zealand Government's Bilateral Aid Programme awarded a study grant to C. S. Jayaweera.

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