

RELATIONSHIP BETWEEN AERIAL SHOOT AND ROOT BIOMASS IN CALIFORNIAN THISTLE

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ABSTRACT

The hypothesis that late autumn root biomass in Californian thistle (*Cirsium arvense*) is a linear function of aerial shoot biomass duration over the previous growing season was tested in experiments conducted in 1995-96 and 1996-97 in sheep-grazed pasture in Canterbury. A range of biomass durations was generated by single and multiple mowings early, midway and late in the growing season. Linear regressions of autumnal root weight on shoot biomass duration explained 26% and 91% of the variation in root mass in 1995-96 and 1996-97 respectively. Mowing was more effective in limiting autumnal root biomass the later in the growing season it was conducted, as a result of the greater impact of later-season defoliation on shoot biomass duration.

Keywords: *Cirsium arvense*, mowing, assimilation, root, shoot.

INTRODUCTION

Defoliation of Californian thistle (*Cirsium arvense*) using grazing animals, mowing or combinations has been advocated as a means of controlling populations of this weed in pastures. This recommendation is soundly based on empirical studies which demonstrate that multiple defoliation events repeated annually, reduce dense shoot populations to a small fraction of their initial size within about three years (Hartley *et al.* 1984; Hartley and Thomson 1981; Mitchell and Abernethy 1993; Donald 1990). The mechanism of this reduction in aerial shoot population size has never been demonstrated but has been assumed to involve an interruption of root development and a consequential reduction in the vegetative reproductive potential and/or size of the root-borne adventitious bud population.

If the form of the relationship between the size of the root and aerial shoot systems was known for Californian thistle, then it would be possible, by incorporating this into a suitable population model, to simulate the effects of many varying defoliation scenarios, including the integration of defoliation with other control options (e.g. a *Sclerotinia sclerotiorum* mycoherbicide). It would thus be possible to develop hypothetically optimal control strategies to achieve defined goals such as "eradication", "stable population at lower density than currently" etc. (Mortimer 1983). The impact of defoliating herbivores intended as biocontrol agents could also be assessed. Specific outputs from such a modelling programme could then be tested by experiment. The model would also need to incorporate information on other important processes. These include how root bud number is related to root weight, and the effects of density dependent and density independent processes on the birth, survival and death of adventitious shoots in a pasture; seedlings can be ignored since they occur only in disturbed habitats such as arable cropping land (Moore 1975; Heimann and Cussans 1996). The current contribution forms part of such a modelling programme. Here we focus on defining the relationship between root weight at the end of the growing season (the variable that sets the potential shoot population next season) and the size of the assimilating shoot system in the current season for a typical sheep pasture population of Californian thistle in Canterbury.

MATERIALS AND METHODS

The first of two experiments (Exp. 1) was conducted from November 1995 until May 1996 in a rotationally grazed (by sheep) and "border-dyke" irrigated grass-clover pasture at Templeton, Canterbury, that was uniformly and heavily infested by Californian thistle. Eight treatments (mainplots) giving all 2 x 2 x 2 factorial combinations of unmown and mown on 21 Nov 1995 (early), 3 Jan 1996 (mid season) and 4 Mar 1996 (late) were allocated at random within two replicates occupying respectively the upper and lower halves of three 10 m wide x 70 m long irrigation borders. The plots were mown to ground level with a 1 m wide Sheen sickle-bar mower. Fifteen sample positions (subplots) measuring 2 m x 2 m were located within each mainplot. This allowed, firstly, for 11 sampling occasions (7 Nov 1995, 21 Nov, 5 Dec, 19 Dec, 3 Jan 1996, 16 Jan, 30 Jan, 4 Mar, 27 Mar, 16 April and 8 May) upon which total dry matter of the aerial shoots of the thistle was determined. Four samples of 0.25 m² each were taken from the centre of the subplots and dried to a constant weight at 85 °C in a forced air oven. Secondly, the other four positions were used to sample the thistles' roots on 30 and 31 May (rep 1) and 5 and 7 June (rep 2) by taking 5 soil cores measuring 155 mm diameter to a depth of 350 mm from each of the four positions. Unfortunately, a rogue mob of sheep ate many thistle shoots throughout the experimental site on ca. 1 Feb 1996. To even up this effect, the whole experimental site was mown to ground level on 8 Feb.

The experiment was repeated (Exp. 2) in an adjacent paddock from November 1996 until May 1997. The paddock was under the same irrigation and stock management regime - although this year the thistles were not eaten by the sheep. All details of the experimental design and sampling methodologies were as before except that the mowing dates varied slightly (25 Nov 1996 (early), 13 Jan 1997 (mid season), 25 Feb 1997 (late)) as did the sampling dates for shoots (25 Nov 1996, 9 Dec, 23 Dec, 13 Jan, 27 Jan 1997, 10 Feb, 25 Feb, 11 Mar, 24 Mar, 14 Apr, 6 May) and roots (6 to 11 Jun 1997). Additionally, this year the experiment was located within four 10 m wide irrigation borders and was mown with a John Deere Ride-on rotocut mower).

From the data, the values of two variables were calculated. Firstly the "shoot biomass duration" (SBD), an estimate of whole season-long opportunity for photosynthetic assimilation by the thistle population's shoot system was derived for each mowing treatment using trapezoidal integration to calculate the area beneath the graph of the total weight of shoots versus time. To achieve this integration, zero shoot biomass was assumed for the mown plots the day after mowing. SBD duration is expressed in g (dry matter) days / m². Secondly, the total biomass of roots per unit area was calculated and expressed in units of g dry matter / m².

The main-effects of, and the interactions between, times of mowing were analysed by ANOVA after transformation of both shoot and root weights to logarithms. The degree to which end-of-season root weight could be explained by the size and duration of the assimilatory aerial shoot system during the growing season, was determined by regression analysis using the raw data means, with the intercept constrained to be zero.

RESULTS

The results of the analysis of variance of the log-transformed shoot and root data are in Table 1. In Exp. 1 there was no evidence of an effect of mowing on SBD of the thistle population although root yield was reduced 48% ($P < 0.01$) by late mowing. By contrast, in Exp. 2, all mowing treatments reduced SBD and root yield. The main-effect of early, mid-season and late-season mowing was a reduction in SBD of 31%, 31% and 59% and a reduction in root yield of 27%, 40% and 59% respectively (Table 1). Two other features of these data are (1) the lack of any interactions between mowing times and (2) the greater SBDs and root yields in Exp. 2 (Table 1).

Root yield was positively correlated to SBD in both experiments but the relationship was much stronger in Exp. 2 ($r = 0.952^{**}$) than in Exp. 1 ($r = 0.505^{ns}$). The fitted linear regressions are given in Figure 1. In both experiments, the regression model was simplified from $y = a + bx$ to $y = bx$, since the intercept parameter, a , was not significantly different from zero. The good fit of the data to the model in Exp. 2, and the severely constrained SBD and root yields in Exp. 1, are evident.

TABLE 1: Aerial shoot biomass duration and autumnal root biomass of Californian thistle mowed at different times in the growing season in two experiments in sheep-grazed grass-clover pastures. Data were log transformed. Back-transformed means are presented along with the Least Significant Ratio (LSR (P<0.05)), the smallest ratio between two means which is statistically significant. The significance of the main-effects and interaction terms in the ANOVA are given as: ns = not significant; * = P < 0.05; ** = P < 0.01.

| Time of mowing treatment | Experiment 1 (1995-96) | | Experiment 2 (1996-97) | |
|---|--|---|--|---|
| | Aerial shoot biomass duration (g days/m ²) | Autumnal root biomass (g/m ²) | Aerial shoot biomass duration (g days/m ²) | Autumnal root biomass (g/m ²) |
| None | 4900 | 59 | 22300 | 152 |
| Early | 3600 | 34 | 10800 | 87 |
| Mid | 4400 | 53 | 13700 | 86 |
| Early & Mid | 3700 | 51 | 11700 | 97 |
| Late | 4500 | 28 | 8800 | 76 |
| Early & Late | 3400 | 19 | 6400 | 51 |
| Mid & Late | 3700 | 24 | 4900 | 35 |
| Early, Mid & Late | 3800 | 22 | 3800 | 24 |
| LSR (P < 0.05) | 2.62 | 2.00 | 1.57 | 1.71 |
| Significance of main effects and interactions | | | | |
| Early | ns | ns | ** | * |
| Mid | ns | ns | ** | ** |
| Late | ns | ** | ** | ** |
| Early x Mid | ns | ns | ns | ns |
| Early x Late | ns | ns | ns | ns |
| Mid x Late | ns | ns | ns | ns |
| Early x Mid x Late | ns | ns | ns | ns |

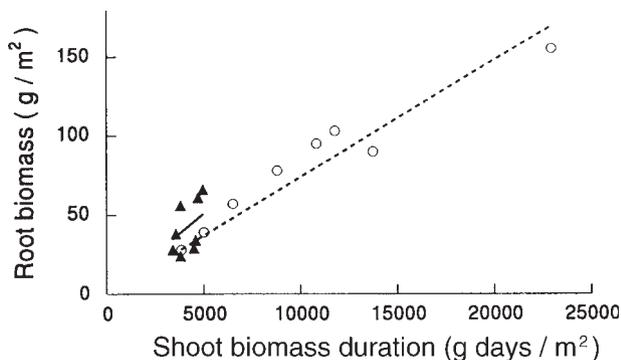


FIGURE 1: The relationships between autumnal root biomass (g/m²) and aerial shoot biomass duration (g days/m²) in Californian thistle in Exp. 1 (1995-96) [▲—▲] and Exp. 2 (1996-97) [○—○]. The fitted regressions are respectively $y=0.0102x$ ($R^2=0.255$) and $y=0.0074x$ ($R^2=0.905$).

DISCUSSION

The main purpose of this work was to test the hypothesis that end-of-season root yield in Californian thistle is directly proportional to the biomass duration of the aerial shoot system over the preceding growing season. The basis for this hypothesis comes from crop physiology theory which predicts that a non-photosynthetic assimilate 'sink', such as grain yield in e.g. cereal crops, will be a linear function of the whole season-long opportunity that the crop has for assimilation (Hunt 1990). In crop physiology, leaf area duration (LAD) is usually used to quantify this assimilatory opportunity, but we have used shoot biomass duration (SBD), a more readily and accurately measured attribute in Californian thistle, where the stiff and convoluted leaf surface makes leaf area measurement very difficult. The results from Exp. 2 provide very strong support for our hypothesis, since the linear regression of root yield on SBD fits the data extremely well (Figure 1). The much poorer relationship found in the data from Exp. 1 is explicable on the basis of the extreme truncation of the upper range of SBD, brought about by the mowing of all treatments in mid season to even-out the severe and irregular shoot damage done by the rogue flock of sheep.

Since the y intercept in our regressions (parameter a) can be set to zero, we can conclude that there will be no roots present in autumn if there has been no assimilatory opportunity during the preceding growing season. This result implies not only an absence of new root production in the absence of foliage, but also the loss, by autumn, of the entire root system that exists at the beginning of the growing season. The latter can be explained either by an absolute requirement for current photosynthate to support existing roots, or by a naturally high turn-over of roots such that roots that have overwintered, die by the end of the growing season, being completely replaced by newly produced roots from which the next season's shoot population arises. The latter hypothesis is supported by our observations of dead roots throughout the growing season in intact (non-mown) populations of the thistle in Canterbury sheep pastures.

The extent to which the relationship between root yield and SBD found in this study is a constant physiological attribute of Californian thistle needs to be confirmed by further experiments with a range of biotypes under varying environmental conditions. This relationship would then be of considerable value in predicting the consequences for population growth, of any intended control measure (biological, mechanical, chemical etc.) that lowers the SBD of a Californian thistle population. This is made possible by the existence of another physiological constant in this thistle; the ratio of the number of adventitious root buds to the weight of the roots (Bourdôt unpublished data). Thus the size of the root bud population, and hence the size of next season's shoot population, may be predicted from SBD in the current season.

An immediate practical implication of the linear root yield - SBD relationship is that the more frequently a farmer mows, or otherwise defoliates a Californian thistle population, the lower will be the overwintering root mass. Since at typical population densities (ca. 40-50 shoots/m²), there is a linear relationship between the size of the spring time shoot population and the overwintered root mass (Bourdôt *et al.* 1995), the more defoliations during a growing season reduce shoot biomass duration, the lower will be the size of the shoot population in the following year. The current study indicates that mowing late in the season will reduce root yield, and thus overwintering root mass, more than mowing earlier in the season. This is explicable by the lack of opportunity for shoot biomass recovery from late season defoliation and because late season mowing effectively destroys the assimilatory system when it is maximal, and most capable of supporting root growth.

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