Root versus shoot measurements to evaluate recovery of Canada thistle (*Cirsium arvense*) after several years of control treatments

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Donald, W. W. 1993. **Root versus shoot measurements to evaluate recovery of Canada thistle (*Cirsium arvense*) after several years of control treatments**. Can. J. Plant Sci. **73**: 369–373. Several methods were compared for estimating long-term control of Canada thistle [*Cirsium arvense* (L.) Scop.] after ending several years of herbicide treatment. Simple linear regression equations using shoot density m^{-2}, numbers of adventitious root buds, or root fresh weight, measured in late summer after several years of herbicide treatment, were equally accurate in estimating Canada thistle shoot density m^{-2} in early June of the following year (R^2 = 0.77–0.81). In contrast, shoot density m^{-2} measured in late summer estimated shoot density m^{-2} in late summer of the following year more accurately (R^2 = 0.93) than did either root growth variable (R^2 values = 0.80–0.83).

Key words: Adventitious root buds, perennial weed, root

Donald, W. W. 1993. **Valeur des mesures des racines ou des parties aériennes de la plante pour prédire la reprise du chardon des champs (*Cirsium arvense*) après plusieurs années de lutte chimique**. Can. J. Plant Sci. **73**: 369–373. Plusieurs méthodes ont été comparées pour estimer l'efficacité de la maîtrise à long terme du chardon des champs [*Cirsium arvense* (L.) Scop.] au terme de plusieurs années de traitement chimique. Les équations de régression linéaire simple utilisant la densité des pousses par m^2, le nombre de bourgeons de racines adventives ou le poids des racines fraîches mesurés en fin d'été après plusieurs années de traitement herbicide se sont montrées toutes aussi efficaces pour prédire la densité par m^2 du chardon au début de juin de l'année suivante (R^2 = 0,77 à 0,81). En revanche, la densité des pousses de chardon par m^2 mesurée en fin d'été fournissait une prédiction plus juste (R^2 = 0,93) de l'infestation un an plus tard, que n'importe laquelle des variables de la croissance racinaire (R^2 = 0,80 à 0,83).

Mots clés: Bourgeon de racine adventive, mauvaise herbe pérenne, racine

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In most short-term research, perennial weed control is usually measured directly, commonly as either visually evaluated percent weed control, weed density, or weed shoot biomass per area, or indirectly, as crop yield (reviewed in Donald (1990)). Because long-term control of perennial weeds is studied less frequently, there is no agreement on which variables should be measured to estimate residual control. One way to assess residual control is to stop treatment and measure subsequent weed resurgence, usually by following changes in shoot density over time. Canada thistle [*Cirsium arvense* (L.) Scop.] is a persistent problem weed from year to year because new shoots arise from adventitious root buds on the weed's extensive, perennial, spreading root system (Moore 1975; Donald 1990). With this weed, it might be possible to estimate later infestations from measurements of root biomass or adventitious root buds, made soon after ending treatment.

Although researchers often use weed shoot density to measure short-term control within a growing season, shoots are not weed "propagules", such as seeds. In Canada thistle, adventitious root buds and root fresh weight are largely responsible for both vegetative propagation of shoots from roots and persistence of established patches of this perennial weed on farmland (Donald 1990). Because Canada thistle seed does not persist very long in soil (Moore 1975) and seedlings emerge poorly in the field, seeds are not

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thought to be responsible for the persistence of this species after patch establishment (Donald 1990).

The objective of this experiment was to compare several methods for predicting Canada thistle shoot density as it recovers after several years of control treatments. Previously published information on this data set (Donald 1992; Donald and Prato 1992) dealt only with comparing the relative efficacy of herbicides in individual years, not predicting relationships between weed growth variables between seasons. Earlier, a randomized complete block design with three blocks was used on two adjacent sites (Trials 1 and 2, respectively) to study the effect of 10 herbicide treatments on Canada thistle over time (Donald and Prato 1992). Trial 1 lasted from the fall of 1983 to 1988 and trial 2 lasted from the fall of 1984 to 1989. Individual plots measured 3.0 by 12.2 m in both trials. Repeated herbicide treatments resulted in a range of Canada thistle shoot densities in year 4, the last year of spring herbicide treatment, and year 5. The two trials were mechanically fallowed using a field cultivator-harrow for weed control in year 5. It was assumed for the analyses presented here that the herbicide treatments served only to create 30 different Canada thistle densities. The previous experimental design was ignored.

Canada thistle shoots arising from adventitious root buds were counted in eight randomly placed 0.5-m^2 square quadrats per plot in late summer of year 4 and again in the spring and late summer 1 yr later (year 5) (Table 1) (Donald and Prato 1992).

A hydraulically powered, tractor-mounted soil corer (Giddings Machine Co., P.O. Drawer 2024, Ft. Collins, CO 80522) was used to take 15 cores (6.4 cm diameter by 50 cm deep) per plot in late summer of year 4 (Table 1). Three cores were taken from the center of each of five equally spaced subplots 0.6 m inside plot borders. Reportedly, this depth includes most roots (Lauridson et al. 1983; Nadeau and Vanden Born 1989). Thickened roots were extracted from the soil cores using a root washer (Carlson and Donald 1986, 1988). Root fresh weight and visible adventitious root bud numbers were determined after pooling all root samples from each plot. Thickened roots that produce shoots from adventitious root buds (Moore 1975; Donald 1992) are defined as those not passing out of a 14-mesh screen (≥ 1.3 mm diameter) during extraction from soil. Small lateral roots and elongating, unthickened portions of primary roots do not form shoots from root buds (Hamdoun 1972; Prentiss 1889). Numbers of adventitious root buds measured to a depth of 50 cm were expressed in terms of soil surface area (m^{-2}) so that data could be compared with shoot density m^{-2} directly. Numbers of adventitious root buds m^{-3} can be calculated by multiplying by 2 the adventitious root bud numbers m^{-2} reported here. Shoot density m^{-2} measured in spring was 117 ± 15% (means ± standard error) of the shoot density m^{-2} measured late in the previous summer and 4.2 ± 0.6% of the adventitious root buds m^{-2} when averaged for pairs of measurements > 0. Thus, shoot density in spring represented only a small proportion of the surviving root bud bank.

Table 1. Dates when field observations were made

	Trial 1		Trial 2	
	Year 4	Year 5	Year 4	Year 5
Observation	1987	1988	1988	1989
Canada thistle shoot density determined				
in spring	06/01	06/07	06/08	05/09
in late summer	07/27	08/12	07/26	07/19
Canada thistle roots				
sampled	09/1-2	—	09/8-12	—
processed	09/3-9	—	09/9-13	—

Linear regression equations were calculated (Tablecurve version 3.0 software, Jandel Scientific, 65 Koch Road, Corte Madera, CA 94925; SPSS/PC$^+$ version 4.0, SPSS Inc., 444 N. Michigan Ave., Chicago, IL 60611), using the method of least squares (Kleinbaum and Kupper 1978; SPSS 1990) for relationships between shoot density m^{-2} in spring at the usual time of broadleaf herbicide application before mechanical fallow was started (mid-May to early June) or in late summer (late July to mid-August) just before the usual time of wheat harvest (mid-July to mid-August) in year 5 as a function of shoot density m^{-2}, root fresh weight m^{-2}, or adventitious root bud density m^{-2} in late summer of year 4 (mid-August to early September) (Table 1). Coefficients of determination (R^2) and inspection of plots of residuals versus the independent variable were used to evaluate the adequacy of each regression equation (Kleinbaum and Kupper 1978). R^2 values represent the proportion of variability that can be attributed to the independent variable in the regression equation. The Y-axis intercept (a) and coefficients of the slope (b) for regression equations having the greatest R^2 value also were tested for the null hypothesis that they were not different from zero. Data for both trials were combined because there were no significant differences in regression equations between trials using trial as a dummy variable (analysis not presented) (Kleinbaum and Kupper 1978).

Canada thistle shoot density m^{-2} in the spring (early June) or late summer (late July to mid-August) was a positive linear function of shoot density m^{-2} measured in late July the previous year and of root fresh weight m^{-2} or adventitious root bud density m^{-2} to a depth of 50 cm measured in early September of the previous year (Fig. 1). These regression equations accounted for most data variability: R^2 values were high, ranging from 0.77 to 0.93. Because plots of residuals versus each independent variable for each equation were randomly distributed around zero, more complex regression equations were unwarranted. This is the first report that Canada thistle shoot density m^{-2} or root growth in one growing season is linearly related to shoot density m^{-2} at various times in the following growing season.

Both Canada thistle shoot density m^{-2} and root variables measured in late summer were equally accurate in estimating shoot density m^{-2} in the following spring within a trial (Fig. 1a-c). This conclusion is supported by similar R^2 values (R^2 = 0.77–0.81) for these regression equations for each independent variable.

Y intercepts for estimated shoot density m^{-2} in spring were greater than zero ($P \leq 0.05$ or less) even when no shoots or root growth were observed late in the previous summer (Fig. 1a-c). This inaccuracy was probably caused by sampling error. The detection limit for shoot density m^{-2} was 0.25 shoot m^{-2} assuming that one shoot was counted per four m^2 samples ($= 8 \times 0.5\ m^2$ quadrats per plot). Detection limits for adventitious root buds and root fresh weight were 20.7 root buds m^{-2} and 0.21 g m^{-2}, respectively, assuming that 1 root bud and 0.01 g fresh weight of roots were found in 15 cores per plot. Detection limits for root variables to a depth of 50 cm were calculated per m^2 soil surface area (15 soil cores with 6.4 cm diameter per plot). Shoot density m^{-2} was determined by sampling 11% of the plot area per treatment, but root samples represented only 0.13% of the total surface area per plot, respectively. The cost and time required for root sampling precluded greater numbers of samples.

This inaccuracy may limit the usefulness of such regression equations for estimating shoot density m^{-2} in spring when Canada thistle shoot density m^{-2} is close to zero. For example, in trial 2, fall-applied glyphosate at 1.7 kg ha^{-1} for 2 yr either alone or combined with spring-applied bromoxynil + MCPA at 280 + 280 g ha^{-1} for 4 yr resulted in shoot densities of 1.5 (± 0.9) (mean ± standard error) and 0 shoots m^{-2} at harvest in year 4, respectively, and no detectable root fresh weight in the soil profile down to 50 cm (Donald 1992; Donald and Prato 1992). Nevertheless, shoot densities in the spring of year 5 in these treatments were 3.9 and 0.1 shoots m^{-2}, respectively.

In contrast to the regression equations for estimated Canada thistle shoot density m^{-2} in spring, the independent variables were not equally accurate in estimating shoot density m^{-2} in late summer of the following growing season (Fig. 1d-f). Shoot density m^{-2} in late summer estimated shoot density m^{-2} late in the following summer more

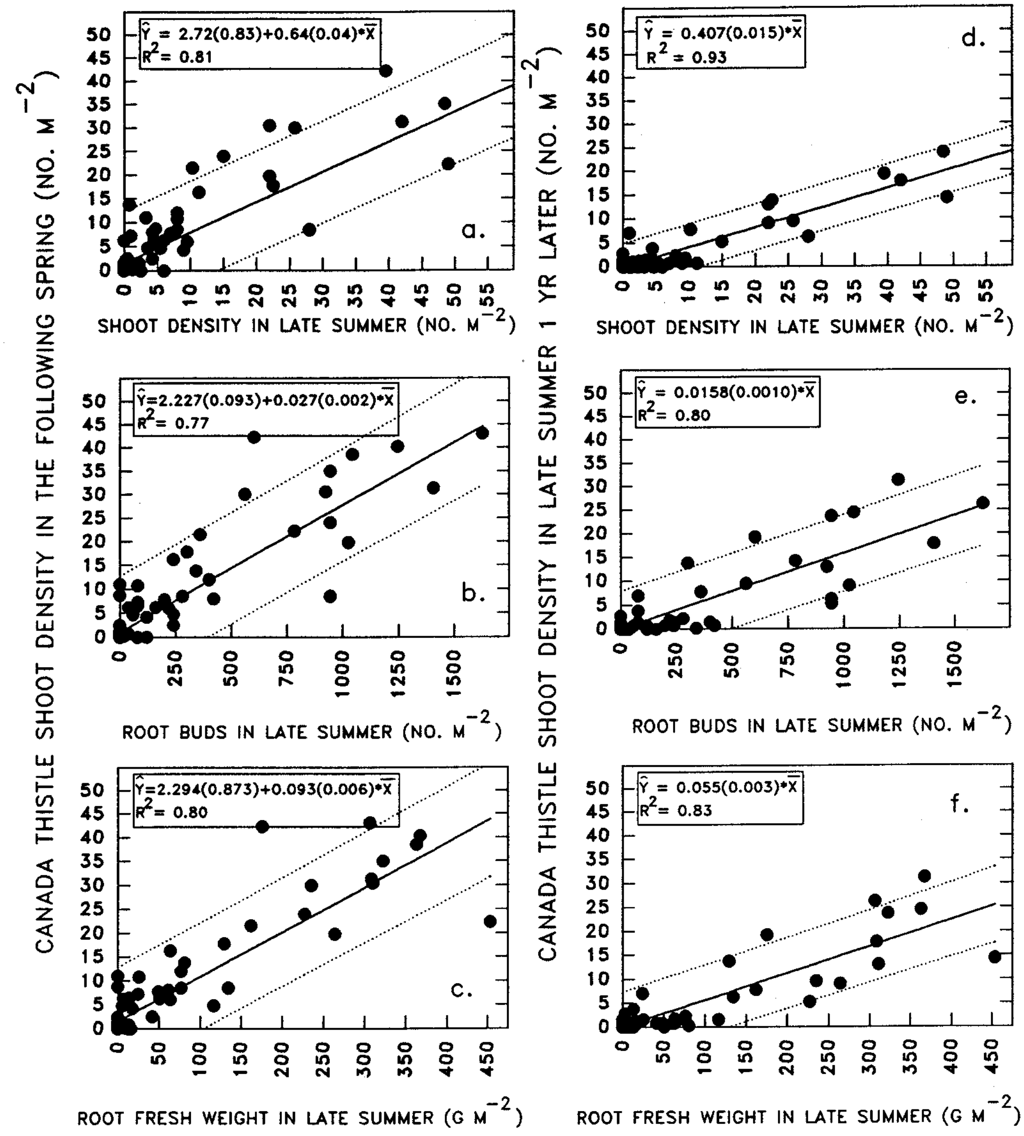

Fig. 1. Relationship between numbers of Canada thistle shoots in spring (early June) or late summer (late July to early August) and numbers of shoots, thickened roots and adventitious root buds the previous fall for two trials ($N=60$). Fitted line (solid line), observations (filled circles) and 95% prediction interval (dashed lines) are presented. Slopes (± standard error of the slope in parentheses) are presented. All coefficients were greater than zero ($P \geq 0.05$ or less).

accurately ($R^2 = 0.93$) than did adventitious root buds ($R^2 = 0.80$) or root fresh weight ($R^2 = 0.83$). Equations for estimating shoot density m^{-2} in late summer forced through the origin could not be distinguished statistically from those that were not forced through the origin (data not presented) (Kleinbaum and Kupper 1978).

It is advantageous to use shoot density to estimate residual long-term Canada thistle control in preference to root growth. Shoot density m $^{-2}$ can be measured more quickly and cheaply than either root variable. Only quadrats were required for measuring shoot density m $^{-2}$, whereas collecting, extracting, and quantifying root variables required expensive equipment (Carlson and Donald 1988). Sampling shoot density m $^{-2}$ was nondestructive, allowing the same shoots to be recounted over time, if desired, whereas root sampling was destructive; different soil cores were sampled over time. Shoot measurements did not disturb the soil profile in contrast to root sampling. Shoots were inherently less ambiguous to identify than were Canada thistle roots; experience would have been required to distinguish Canada thistle roots from those of other perennial species, such as quackgrass [*Agropyron repens* (L.) Beauv.], perennial sowthistle (*Sonchus arvensis* L.), or field bindweed (*Convolvulus arvensis* L.) if these perennial weeds had also been present. Consequently, root measurement should be made only where Canada thistle is the sole perennial weed present, as was done in this study. Greater numbers of samples can be taken for shoots m $^{-2}$ than for root growth because it is physically possible to sample only a limited number of soil cores with available technology (Carlson and Donald 1986).

This is the first report that estimated Canada thistle shoot density m $^{-2}$ is a linear function of either shoot density m $^{-2}$ or root growth measured in the previous growing season. Estimated shoot density combined with estimated relative yield loss due to Canada thistle (Donald 1990) may have potential for evaluating the potential profitability of different control measures using break-even economic analysis, but this possibility remains to be tested. Such an approach may aid farmers in deciding whether or not to continue Canada thistle control measures.

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