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Influence of Grass Weeds on the Yield and Profitability of Field Crops in Western Canada

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INFLUENCE OF GRASS WEEDS ON THE YIELD AND PROFITABILITY OF FIELD CROPS IN WESTERN CANADA

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GENERAL SUMMARY AND PRACTICAL RECOMMENDATIONS

The results of the studies indicate that wild oat, volunteer barley, volunteer wheat and quack grass are highly competitive species and can cause considerable yield and financial losses to Alberta farmers. It was difficult to compare the relative competitiveness of the four species, since the experiments were conducted during different years, at different locations and under variable environmental conditions. However, calculated linear regression coefficients from this and other studies suggest that volunteer barley may be most competitive, followed by volunteer wheat, wild oat and quack grass.

Regression analysis of yield data from field experiments conducted at Vegreville and Lacombe, Alberta indicated that there was a signficant relationship between yield loss of barley (Hordeum vulgare L.) and wheat (Triticum aestivum L.), and relative time of emergence of wild oat. Percentage yield loss can be estimated from the nonlinear equations,

$$Yl = \frac{0.503d}{e^{0.266t} + 0.503d/49.1}$$ for barley, and

$$Yl = \frac{0.600d}{e^{0.199t} + 0.600d/104.6}$$ for wheat,

where:

Yl = percentage crop yield loss,

t = relative time of wild oat emergence (days),

d = wild oat density (plants/m^2), and

e = the base of natural logarithms.

The equations predict that at a given wild oat density, percentage yield loss increased the earlier wild oat emerged relative to the crop and gradually diminished the later it emerged. Barley was a better competitor than wheat, and was less affected by late emerging wild oat. The results suggest that wild oat seedlings which emerge late relative to the crop may have little impact on yield, especially in the case of barley. Controlling these weeds with a herbicide may therefore be uneconomical. In fields where wild oat is a problem farmers should strive to ensure that the crop establishes well ahead of the weeds to avoid serious yield losses. Good clean seed should be planted in a warm, firm and moist seed bed. This will ensure rapid establishment of the crop. Timely tillage is also important, and crop seeding should proceed as soon as possible after the last cultivation. The use of a strong competitive crop such as barley will help suppress the wild oat, with minimal yield losses.

The effects of different densities of volunteer barley and volunteer wheat on the yield of canola (_Brassica campestris_ L. "Tobin" and _B. napus_ L. "Westar"), and the seed yield of the volunteer cereals were determined in field experiments conducted at Vegreville and Lacombe, Alberta and Scott, Saskatchewan. Nonlinear regression analysis indicated that there was a significant relationship between canola yield loss and volunteer cereal density. Percentage canola yield loss can be estimated from the equations,

$$Yl = \frac{1.7d}{1 + 0.0097c + 0.017d}$$ for volunteer barley and,

$$Yl = \frac{3d}{1 + 0.04c + 0.03d} \quad \text{for volunteer wheat,}$$

where:

Yl = percentage canola yield loss,

d = volunteer cereal density (plants/m^2), and

c = canola density (plants/m^2).

The equations predict that both volunteer cereals can severely reduce canola yields with losses increasing with increasing volunteer cereal density. Canola density also influenced the extent of the yield losses caused by the cereals. At a given volunteer cereal density, canola yield losses diminished as canola density increased. This suggests that canola should be seeded at higher than normal seeding rates in situations where volunteer cereals and other weeds are expected to be a problem, and particularly when chemical control of the weeds is not anticipated.

Volunteer cereals differ from other weeds in that the seed produced may have a market value. Potential volunteer cereal yields can be estimated from the equations,

$$Yb = \frac{0.057d}{1 + 0.007c + 0.015d} \quad \text{for volunteer barley}$$

and

$$Yw = \frac{0.034d}{1 + 0.018c + 0.012d} \quad \text{for volunteer wheat}$$

where:

Yb and Yw = volunteer barley and volunteer wheat yield, respectively

d = volunteer cereal density (plants/m^2), and

c = canola density (plants/m^2).

Revenue losses due to reduced canola yield can be alleviated when the value of the volunteer cereal is considered. This provides the farmer with the option of harvesting both the canola and volunteer cereal rather than controlling the volunteer crop with a herbicide. This option, however, will only be feasible when the volunteer cereal is the main grass weed and where populations of other weeds such as wild oat and green foxtail are low. This situation would occur where a farmer has used a preemergence herbicide such as trifluralin, which would control wild oat and green foxtail, but not volunteer barley or wheat.

The effects of different shoot densities of a natural infestation of quack grass (Agropyron repens [L] Beauv.) on the yield of canola were determined in field experiments conducted near Vegreville, Alberta. Nonlinear regression analysis indicated that there was a significant relationship between canola yield loss and quack grass shoot density. Potential canola yield loss can be estimated from the equation,

$$Yl = \frac{0.41d}{1 + 0.41d/141}$$

where:

Yl = percentage canola yield loss, and

d = quack grass density (shoots/m^2).

The equation predicts that quack grass can severely reduce canola yields with losses increasing with increasing quack grass density. These severe yield losses, coupled with the potential for quack grass to spread rapidly throughout a field by means of rhizomes, highlights the importance of controlling this weed. Intensive tillage resulting in starvation and dessication of the rhizomes will provide some control. However, this approach may not be feasible where soil erosion is a problem. A combination of cultural and chemical methods is the most appropriate way to control quack grass.

The equations developed in these studies provide a means of estimating crop losses due to some of our major grass weeds, and thus provide a basis for determining the economic threshold, or weed density at which chemical control of the weeds is economical. To get an accurate estimate of the potential yield loss due to the weeds, a farmer should take random counts of the weed seedlings (and crop seedlings where required) present in the field, prior to applying a postemergence herbicide. A quadrat (minimum 0.25 m^2) should be used during the counting procedure. The more samples taken, the greater will be the accuracy of the yield loss estimate, but at least 20 samples should be taken on a 32 ha field. For best results, the field should be crisscrossed in a "W" pattern and counts taken at every 20 paces. The average of the total number of samples should then be determined and converted to plants/m^2, prior to estimating percentage yield loss from the equations.

To estimate if weed control with a herbicide is economical, several other factors need to be considered. These include the market price of the crop, and the expected weed-free crop yield. In the case of volunteer cereals, the market price of the cereal and the cost of separating the cereal from the canola seed should also be taken into account, since these will influence the economic threshold. Generally, higher crop prices and expected weed-free yields will favour control with herbicides, while lower prices and yields will favour omitting control. Relatively low canola prices and yields may favour harvesting volunteer cereals with the canola, rather than controlling them with a herbicide.

GENERAL INTRODUCTION

Weeds cause billions of dollars in lost revenue in North America each year. A recent report (Chandler et al., 1984) estimated average annual losses due to weeds in the United States and Canada at $7.5 billion and $909 million, respectively.

Weeds compete with crops for valuable environmental resources such as soil moisture, soil nutrients and light. The process is complex, and the extent of the competition and subsequent effects on crop yield are dependant on a number of factors. These are depicted schematically in Fig. 1 and include crop and weed species, duration of competition, and time of emergence of the crop and weed. Further influences are exerted by the prevailing soil and climatic conditions such as soil moisture, soil nutrient status and sunlight.

For the producer, the end result of competition from weeds is reduced crop yields and revenues. Although effective herbicides are now available for the control of most serious weeds in field crops in western Canada, the relatively high cost of some of these herbicides can prohibit their use, especially during times of low grain and oilseed prices. This is particularly true of herbicides for grass weed control, where the cost is usually higher than for broadleaf weed control. For example, control of wild oat and volunteer cereals with sethoxydim can cost more than $40 per hectare, whereas annual broadleaf weeds can be controlled with 2,4-D or MCPA for as little as $5 per hectare. In addition to herbicide costs, other factors such as expected crop yields and crop market prices should be

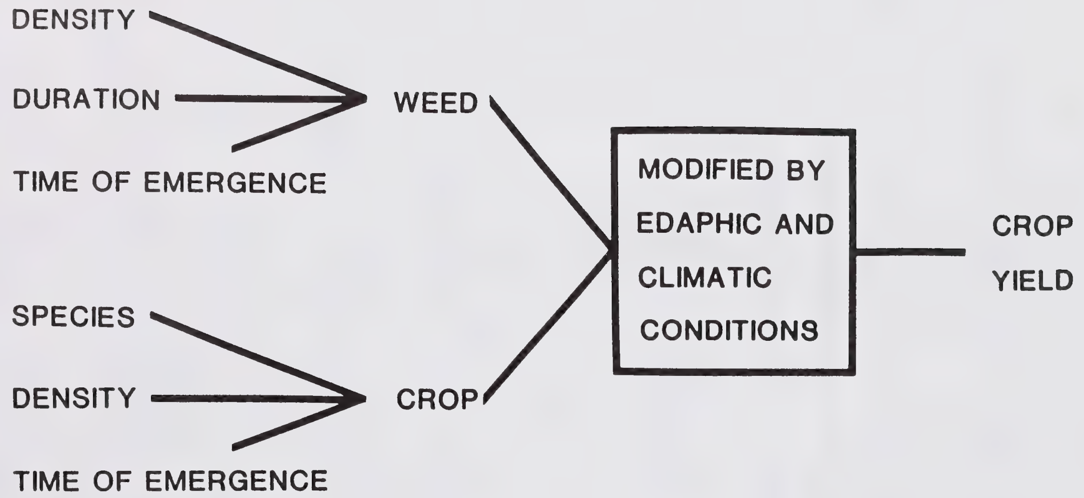

Figure 1. Factors influencing weed-crop competition.

considered when assessing the economics of spraying. Consideration of all of these factors will allow the determination of the economic threshold which for the purpose of this report is defined as the minimum weed population that is justifiable to control within a growing season.

The objectives of this study were to determine a) the effects of wild oat, volunteer wheat and barley, and quack grass on crop yield; and b) the cost-benefit of controlling these weeds with herbicides.

The report has been divided into three sections, each dealing with wild oat in cereals, volunteer cereals in canola and quack grass in canola.

SECTION 1.

INFLUENCE OF WILD OAT ON YIELD AND PROFITABILITY OF BARLEY AND WHEAT

ABSTRACT

Analysis of yield data from field experiments conducted at Vegreville and Lacombe, Alberta using multiple regression and nonlinear hyperbolic models indicated that there was a significant relationship between yield loss of barley (_Hordeum vulgare_ L.) and wheat (_Triticum aestivum_ L.), and relative time of emergence of wild oat (_Avena fatua_ L.). At a given wild oat density, percentage yield loss increased the earlier wild oat emerged relative to the crops and gradually diminished the later it emerged. However, the magnitude of the yield loss for both crops varied with the year. The nonlinear model provided only a slightly better description of the data than the multiple regression model, but avoided a number of undesireable, implausible properties inherent in the more frequently used approach. Both models indicated that barley is a better competitor than wheat and is less affected by late emerging wild oat. Economic threshold wild oat densities varied from 18 to 120 plants/m^2 when different crop yields and prices were considered, and it was assumed that wild oat and crops emerged close to the same time.

INTRODUCTION

Wild oat is one of the most economically harmful annual grass weeds of cultivated land in North America, Europe and Australia. Projected annual wheat and barley losses due to the weed in North America have been estimated at 6.4 million tonne (Nalewaja, 1977). Wild oat is found in all Canadian provinces but causes the greatest economic losses in the three prairie provinces. It has been estimated that 17.3 million hectares of arable land in this region are infested with wild oat of which 13 million hectares have a moderate to heavy infestion of 150 plants/m^2 or greater (Alex, 1966). Annual crop losses and herbicide costs due to wild oat in western Canada alone have been estimated at $280 million (Dew, 1978).

Although wild oat can cause economic losses through a number of added costs including dockage, increased transportation, storage and tillage costs, the greatest single cause of losses is reduced crop yields due to direct competition. Several studies have shown that crop yield losses due to wild oat competition increase with increasing wild oat density (Bell and Nalewaja, 1968a; Bell and Nalewaja, 1968b; Bowden and Friesen, 1967; Chancellor and Peters, 1974). Dew (1972) used the data generated in some of these studies to develop indices of competition for predicting barley and wheat yield losses due to wild oat. Further work resulted in the development of a model for predicting rapeseed yield losses (Dew and Keys, 1976). The accuracy of these models was later confirmed for western Canada (Hamman, 1979), and the information is currently being used to determine the economics of controlling different wild oat populations with herbicides in cereal and oilseed crops (O'Donovan and Sharma, 1983).

The models derived by Dew (1972) and Dew and Keys (1976) were based on the assumption that wild oat and the crop emerged at about the same time. Several studies, however, have indicated that the relative time of emergence of wild oat may influence its competitive ability (McBeath et al., 1970; Thurston, 1962). Peters and Wilson (1983) found that a given density of wild oat plants emerging at an early stage caused a greater barley yield loss than the same density emerging later.

To accurately predict crop yield losses due to wild oat it is necessary to examine the relationship between wild oat density and time of emergence, and crop yield loss. Traditionally, in western Canada, weed-crop competition data have been fitted to linear regression models (de St. Remy et al., 1985; Dew, 1972; Dew and Keys, 1976; O'Sullivan et al., 1982; O'Sullivan et al., 1985). Although these models often give a good fit to the data and are easy to use, they possess biologically unreasonable properties (Cousens, 1985a). They are often not constrained to pass through the origin thus predicting yield losses or gains when no weeds are present. Semi-empirical hyperbolic models had many advantages over linear regression models in estimating crop losses due to weeds and should be more widely used (Cousens, 1985b). The models have also been used to describe the relationship between crop yield loss and both weed and crop density (Cousens, 1985a) but relative time of emergence data have never been fitted to a nonlinear model.

The objectives of this study were a) to examine the relationship between time of emergence (as well as density) of wild oat, and wheat and barley yield loss using multiple regression and nonlinear (hyperbolic) models; and b) to examine the economics of controlling wild oat in barley and wheat with herbicides.

EXPERIMENTAL DETAILS

Field Operations

Field experiments were conducted at the Agriculture Canada Research Station, Lacombe, Alberta, during 1972, 1973, 1974, 1975, 1976, 1977, 1982, and 1983 and at the Alberta Environmental Centre, Vegreville, Alberta, during 1983. Due to seeding problems and/or erratic wild oat emergence, wheat data for 1974 and 1982 and barley data for 1977 were not collected.

Experiments were conducted on a silt loam soil (54% sand, 37% silt, 9% clay, 10% organic matter, and pH 5.6) and a sandy loam soil (63% sand, 23% silt, 14% clay, 4% organic matter and pH 6.2) at Lacombe and Vegreville, respectively. Plots were fertilized each year according to the soil test recommendations for barley and wheat.

"Galt" barley was seeded at Lacombe during all years except 1973 when "Conquest" was seeded. "Klondike" barley was seeded at Vegreville. "Park" wheat was seeded at Lacombe between 1972 and 1977, and "Neepawa" was seeded in 1983 at both Lacombe and Vegreville.

From 1972 to 1977, wild oat was seeded between the crop rows while during the other years seeding was at right angles to the crop. Wild oat was seeded to emerge at various intervals ranging from 8 days before to 8 days after the crop from 1972 to 1977, and from 6 days before to 6 days after the crop in 1982 and 1983. In all experiments, time of emergence refers to the time wild oat and/or the crop appeared above the soil surface.

Seeding rates of the crops were those recommended for the regions (approximately 200 plants/m^2). However, actual wheat density (average of all plots) varied from 157 plants/m^2 in 1976 to a maximum of 196 plants/m^2 in 1973, while barley density varied from 151 plants/m^2 in 1975 to 202 plants/m^2 in 1976.

Plot size was 2 by 3 m at Lacombe and 2 by 2 m at Vegreville. Within each plot, a 1-m^2 area was selected. Wild oat counts at emergence and yield data were determined from these areas.

Data Analysis

Each experiment was a randomized complete block design with four replicates. Yield loss data for each experiment were expressed as a percentage of the weed-free yield. Percentage yield loss (*Yl*) for each crop within each year and for data pooled over all years and years and locations were fitted to both multiple regression and nonlinear hyperbolic models using PROC NONLIN in the SAS† statistical package, and the maximum likelihood program (Ross, 1980), respectively.

The multiple regression model was:

$$Yl = b_0 + b_1 X_1 + b_2 \sqrt{X_2} \qquad (1)$$

where:

b_0 = the Yl intercept,

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† SAS Institute Inc. SAS User's Guide: Statistics, Version 5 Edition. Cary, NC: SAS Institute Inc., 1985. 956 pp.

b_1 = the regression coefficient for relative time of wild oat emergence (days),

b_2 = the regression coefficient for number of wild oat plants/m^2,

X_1 = relative time of wild oat emergence expressed in days and

X_2 = wild oat density (plants/m^2), respectively.

Percentage yield loss due to a specific wild oat density at different times of wild oat emergence can be calculated from the equation by assigning to X_1 either a negative value (corresponding to number of days wild oat emerges before the crop), a zero value (corresponding to wild oat and crop emerging at the same time), or a positive value (corresponding to the number of days wild oat emerges after the crop). Square root transformation of wild oat density was used because it accounted for more variation in yield loss in terms of the coefficient of determination (r^2) and provided a better estimate of yield loss at low wild oat densities.

Percentage yield loss data pooled over all years and locations were also fitted to a nonlinear model based on a rectangular hyperbola. This was:

$$Yl = \frac{bd}{e^{ct} + bd/a} \qquad (2)$$

where:

b = nonlinear regression coefficients for wild oat density,

c = nonlinear regression coefficients for wild oat time of emergence,

d = wild oat density (plants/m^2),

e = the base of natural logarithms, and

t = relative time of wild oat emergence (days).

Crop yield data (g/m^2) for individual years were fitted to the model:

$$Y = Ywf\ (1 - Yl/100) \tag{3}$$

where:

Ywf = estimated weed-free yield (t/ha) and

Yl = yield loss model (2)

Economic Analysis

The economics of controlling wild oat with a herbicide was determined using the models:

$$E_1 = (V(1 - L)P)) - (H + A), \text{ and} \tag{4}$$

$$E_2 = V(1 - L)P \tag{5}$$

where:

E_1 = the cash returns ($/ha) when wild oat is controlled with a herbicide,

E_2 = the cash returns ($/ha) when wild oat is not controlled with a herbicide,

A = the herbicide application cost ($/ha),

H = the cost of the herbicide ($/ha),

L = the proportional crop yield loss per unit wild oat density at a specific relative time of emergence of wild oat,

P = the crop market price ($/t),

V = the expected crop yield (t/ha).

Economic threshold wild oat densities were calculated graphically in Lotus 1-2-3[†] using combinations of equations (3), (4) and (5).

[†] Registered trademark of Lotus Development Corporation, 55 Cambridge Parkway, Cambridge, MA 02142.

RESULTS AND DISCUSSION

Estimating Crop Yield Loss Due to Wild Oat

Linear regression constants and coefficients of determination for percentage yield loss regressed against relative times of wild oat emergence and wild oat densities are presented in Tables 1 and 2 for barley and wheat, respectively. With the exception of wheat data for Lacombe in 1983, there were significant relationships ($P < 0.01$ or 0.05) between percentage yield loss of barley and wheat and relative time of emergence of wild oat (b_1) within each year, and for data pooled over years (or years and locations). However, relationships between yield loss and wild oat density were, in most cases, nonsignificant ($P > 0.05$) within years, but were significant ($P < 0.01$) when the data were pooled over years (or years and locations). The relatively slight variations in wild oat density within individual years were probably confounded by differences in times of emergence of wild oat, while differences in densities among years were great enough to exert a significant effect on yield.

Although the multiple regression equations (Tables 1 and 2) are easy to use and in most cases give significant regression coefficients, they possess several shortcomings which lead to biologically unreasonable predictions. For example, when no wild oat plants are present, the equations predict that there will be either a gain or a loss in crop yield, and at low densities of wild oat emerging well after the crop, a gain in yield is predicted. Although this is not biologically implausible, it is extremely unlikely. The model also approaches an infinite yield loss at

Table 1. Estimated parameters of the multiple regression model (standard errors in parentheses) for percentage yield loss of barley as a function of time (days) of emergence of wild oat relative to barley and the square root of wild oat plants/m^2 at emergence †.

Experiment	b_0	b_1	b_2	r^2
1972 L	22.17	-2.55* (1.03)	-0.37 (2.28)	0.18
1973 L	7.71	-1.74** (0.28)	0.11 (2.10)	0.55
1974 L	19.93	-2.72** (0.73)	1.94 (2.10)	0.51
1975 L	- 0.90	-1.31** (0.46)	3.08* (1.36)	0.38
1976 L	-14.74	-2.29** (0.47)	3.37 (1.85)	0.47
1982 L	12.79	-3.68** (0.56)	3.04 (3.65)	0.74
1983 L	18.06	-4.17* (1.96)	2.59 (6.39)	0.22
1983 V	- 8.73	-3.14** (0.30)	2.43 (3.12)	0.87
Pooled Model	-11.90	-2.39** (0.27)	3.32** (0.54)	0.33

† Data were fitted to model 1 (see text, pages 10 and 11).

*, ** Significant at the 5 and 1% levels, respectively.

L denotes Lacombe, V Vegreville.

Table 2. Estimated parameters of the multiple regression model (standard errors in parentheses) for percentage yield loss of wheat as a function of time (days) of emergence of wild oat relative to wheat and the square root of wild oat plants/m^2 at emergence †.

Experiment	b_0	b_1	b_2	r^2
1972 L	25.57	-2.65** (0.44)	1.77 (1.34)	0.54
1973 L	52.31	-2.03** (0.24)	0.35 (1.34)	0.69
1975 L	4.40	-2.17** (0.57)	2.46 (1.40)	0.38
1976 L	45.82	-2.51** (0.44)	1.83 (1.51)	0.57
1977 L	25.92	-2.97** (0.28)	2.45* (1.07)	0.77
1983 L	- 0.77	-0.71 (0.56)	3.30 (2.25)	0.14
1983 V	91.06	-4.58** (0.15)	-3.06 (5.39)	0.67
Pooled Model	8.40	-2.61** (0.19)	3.14** (0.43)	0.52

† Data were fitted to model 1 (see text, pages 10 and 11).

*, ** Significant at the 5 and 1% levels, respectively.

L denotes Lacombe, V Vegreville.

high wild oat density, and an infinite yield gain per unit wild oat density at densities approaching zero.

The nonlinear hyperbolic equations for individual years are presented in Tables 3 and 4. Although there was little or no improvement in the coefficients of determination (r^2 values) over the multiple regression equation, the nonlinear model offers a more biologically reasonable alternative to linear regression. In particular, the nonlinear model does not predict a loss in yield when no weeds are present or a yield increase from late-emerging weeds.

The magnitude of the yield losses for both crops, as predicted by both the multiple regression and nonlinear equations for individual years (Tables 1-4), varied significantly ($P < 0.05$) among years. These differences can be partly attributed to differences in times of emergence of wild oat and wild oat densities among years. However, the relatively low r^2 values for some years (Tables 1-4) indicate that other factors may also have influenced the competitive relationship between wild oat and the crops. The use of different barley and wheat cultivars in the experiments, as well as different methods of seeding wild oat, may have contributed to the variation.

The models based on data pooled over all years and both locations provide estimates of wheat and barley yield losses over a range of wild oat densities at specific times of wild oat emergence relative to barley and wheat. Percentage yield losses derived from the pooled multiple regression and hyperbolic models at wild oat densities of 50, 150 and 300 plants/m^2

Table 3. Estimated parameters of the hyperbolic model (standard errors in parentheses) for barley yield (t/ha) as a function of time (days) of emergence of wild oat relative to barley and wild oat plants/m^2 at emergence †.

Experiment	Observed mean weed-free yield	*Ywf*	*a*	*b*	*c*	r^2
1972 L	4.8	4.8 (0.2)	27.8 (4.9)	18.86 (33.96)	1.247 (0.481)	0.19
1973 L	4.3	4.6 (0.1)	29.4 (3.4)	19.74 (38.74)	4.362 (2.112)	0.55
1974 L	2.7	2.6 (0.2)	71.6 (16.8)	0.908 (0.451)	0.160 (0.079)	0.50
1975 L	3.5	3.6 (0.2)	182.7 (158.4)	0.278 (0.094)	0.038 (0.024)	0.39
1976 L	5.1	5.1 (0.4)	60.5 (7.0)	1.022 (0.735)	0.260 (0.110)	0.49
1982 L	4.5	4.5 (0.3)	93.6 (38.9)	0.790 (0.360)	0.173 (0.084)	0.75
1983 L ††	4.0	4.7 (-)	- 14.8 (-)	0.129 (-)	0.032 (-)	0.17
1983 V	5.3	5.3 (0.2)	57.3 (17.9)	0.212 (0.070)	0.257 (0.092)	0.87
Pooled Model	...	... ...	49.1 (3.7)	0.503 (0.099)	0.266 (0.041)	0.32

† Data were fitted to model (2) (see text, pages 11 and 12).

†† Data were insufficient to allow standard errors to be calculated.

L denotes Lacombe, V Vegreville.

Table 4. Estimated parameters of the hyperbolic model (standard errors in parentheses) for wheat yield (t/ha) as a function of time (days) of emergence of wild oat relative to wheat and wild oat plants/m^2 at emergence †.

Experiment	Observed mean weed-free yield	*Ywf*	*a*	*b*	*c*	r^2
1972 L	6.0	5.9 (41)	47.7 (5.4)	16.58 (29.69)	0.484 (.223)	0.61
1973 L	2.3	2.3 (20)	87.2 (17.8)	1.41 (0.83)	0.121 (.048)	0.70
1975 L	2.6	2.6 (14)	53.5 (9.2)	1.04 (0.78)	0.229 (.106)	0.38
1976 L	2.2	2.1 (17)	99.1 (11.8)	1.47 (0.82)	0.144 (.064)	0.57
1977 L	3.8	3.7 (14)	84.5 (7.2)	1.31 (0.47)	0.209 (.064)	0.73
1983 L	4.6	4.7 (49)	- 57.7 (107.9)	0.29 (0.25)	0.026 (.019)	0.16
1983 V	2.7	2.7 (15)	125.2 (53.9)	0.50 (0.19)	0.160 (.054)	0.64
Pooled Model	...	... ...	104.6 (10.7)	0.60 (0.08)	0.119 (.012)	0.46

† Data were fitted to model (2) (see text, pages 11 and 12).

L denotes Lacombe, V Vegreville.

are presented graphically in Figs. 2 and 3. Both models indicate that for every day wild oat emerged before the crop, yield loss increased by approximately 2.5%. Yield loss gradually diminished by the same amount for every day wild oat emerged after the crop. Yield loss was generally greater for wheat than for barley. Also, the parameters for the effect of relative time of emergence are considerably higher for barley than for wheat indicating that barley is better able to tolerate late-emerging weeds. Control of these weeds may, therefore, be less critical than in wheat. In previous studies, barley was also shown to be more competitive than wheat with wild oat (Dew, 1972). Comparison of the two models (Figs. 2 and 3) indicates that while the lines predicted by the multiple regression model intersect the horizontal axis thus predicting yield enhancement due to late emerging weeds, the nonlinear model always predicts a small yield loss tending towards zero as the crop emerges further ahead of wild oat. For wheat (Fig. 3) the predictions of the two models are similar within the range of the data, whereas for barley (Fig. 2) high and low density predictions are somewhat different for the two models.

Several other studies have shown that wild oat plants that emerged early relative to the crop produced more dry matter, tillers, and seeds per plant than wild oat plants that emerged later (Chancellor and Peters, 1972; McBeath et al., 1970; Peters and Wilson, 1983; Thurston, 1962). These, and our study, confirm the belief that earlier germinating plant species gain an advantage over later germinating species and become better established to compete for important environmental resources such as soil moisture, soil nutrients, and light. The earlier emerging species produce larger root systems and above-ground shoots than later emerging species, thus

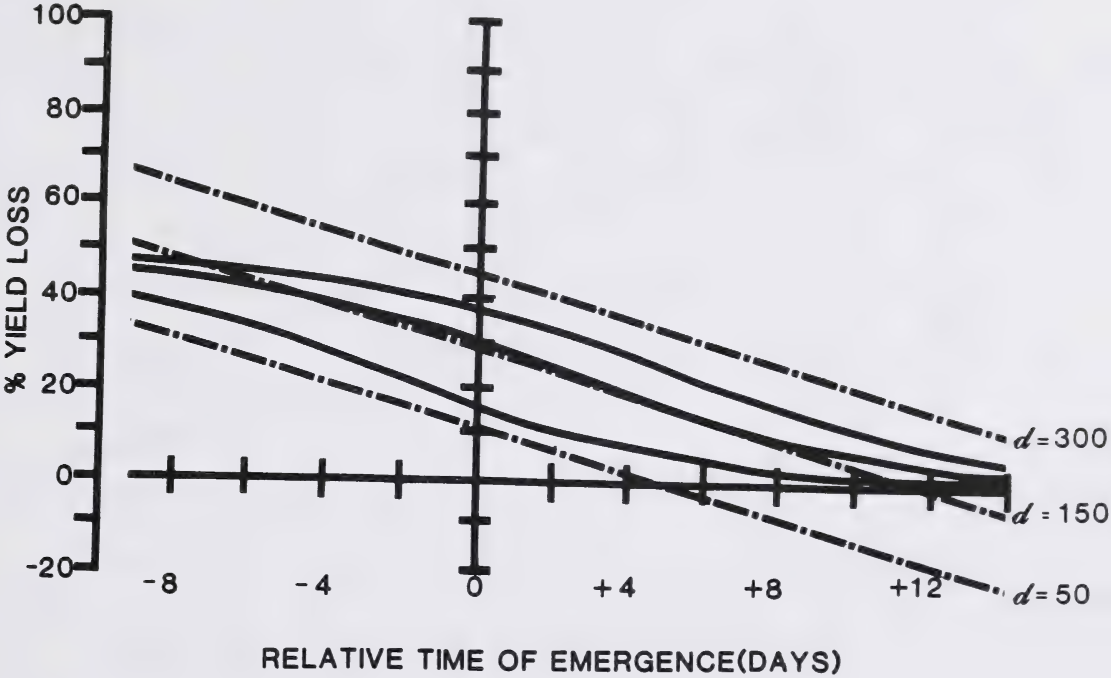

Figure 2. Influence of wild oat emergence at various intervals before the crop (-), at the same time as the crop (0) and at various intervals after the crop (+) on yield loss of barley.

Data were fitted to model 1 (broken lines) and model 2 (solid lines) (see text, pages 10 and 11). *d* = wild oat plants/m^2.

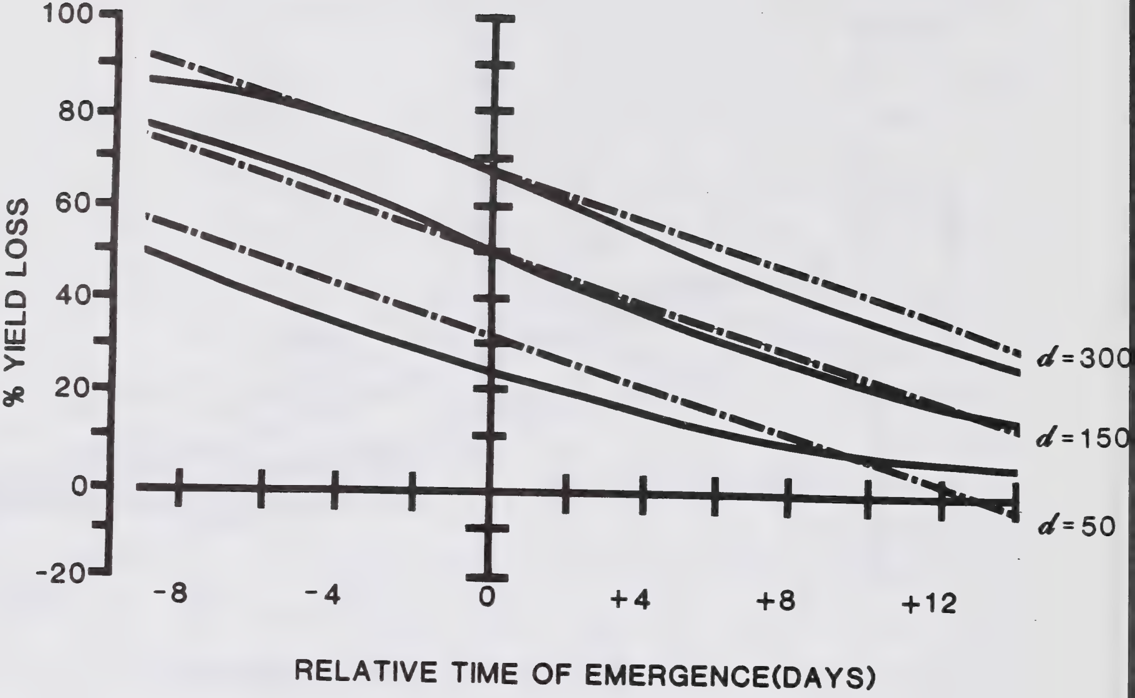

Figure 3. Influence of wild oat emergence at various intervals before the crop (-), at the same time as the crop (0) and at various intervals after the crop (+) on yield loss of wheat.

Data were fitted to model 1 (broken lines) and model 2 (solid lines) (see text, pages 10 and 11). *d* = wild oat plants/m^2.

achieving a competitive advantage. Pavlychenko and Harrington (1934) showed that, although wild oat eventually produced more root material than barley or wheat, root growth of wild oat seedlings was slow compared to cereal crops. This suggests that the weed is most sensitive to competition for soil resources during the early stages of growth. In situations where wild oat germinates earlier than the crop, this advantage of the crop over the weed may be reduced. The earlier emerging wild oat may also be in a better position to compete for light with the cereal crop. Wild oat has been shown to reduce the radiation intensity in a wheat stand by 16 to 37% (Wimschneider and Bachtalor, 1979).

Our study confirms the view of Dew (1972) who suggested that the relative time of emergence of wild oat and the crop would affect the severity of yield loss and alter the index of competition. Our equations, therefore, offer a more accurate means of predicting barley and wheat yield losses than previous models in situations where there are differences between time of emergence of the weed and the crop. At a given wild oat density, crop yield losses may differ considerably depending on the relative time of emergence of the crop and the weed. Our information (particularly the nonlinear model) should be considered, therefore, when assessing losses due to wild oat.

Cost Analysis of Wild Oat Control

The economic threshold weed density will be influenced by factors such as the extent of the crop yield loss, the cost of control, the expected weed-free yield and the crop market price (Marra and Carlson, 1983; Cousens et. al., 1985). The relationship between controlling wild oat with a herbicide (E_1) and not controlling it (E_2) is presented graphically in Figs. 4 and 5 for barley and wheat, respectively. The assumptions are:

Market price of barley = \$90/t,

Expected wild oat-free barley yield = 3.5 t/ha,

Market price of wheat = \$190/t,

Expected wild oat-free wheat yield = 2.5 t/ha,

Herbicide cost = \$34/ha,

Herbicide application cost = \$7/ha.

It is also assumed that the wild oat and crop emerged close to the same time and that all of the potential crop yield would be recovered following herbicide use. This may not always be the case under field conditions, especially where spraying is delayed and/or wild oat infestations are heavy.

At these prices and costs, the economic thresholds for wild oat control in barley and wheat were 35 and 18 wild oat shoots/m^2, respectively (Figs. 4 and 5). However, barley and wheat yields can vary considerably in western Canada depending on soil and climatic conditions and farm management practices, while crop prices also vary according to supply and demand. These factors will influence the economic threshold and determine whether weed control is economical. Economic threshold wild oat densities at different crop yields and prices were calculated and are presented for barley and wheat in Tables 5 and 6, respectively. It is assumed that herbicide and application costs remained constant at \$34 and \$7/ha, respectively. Generally, the economic thresholds decreased as crop yields and prices increased.

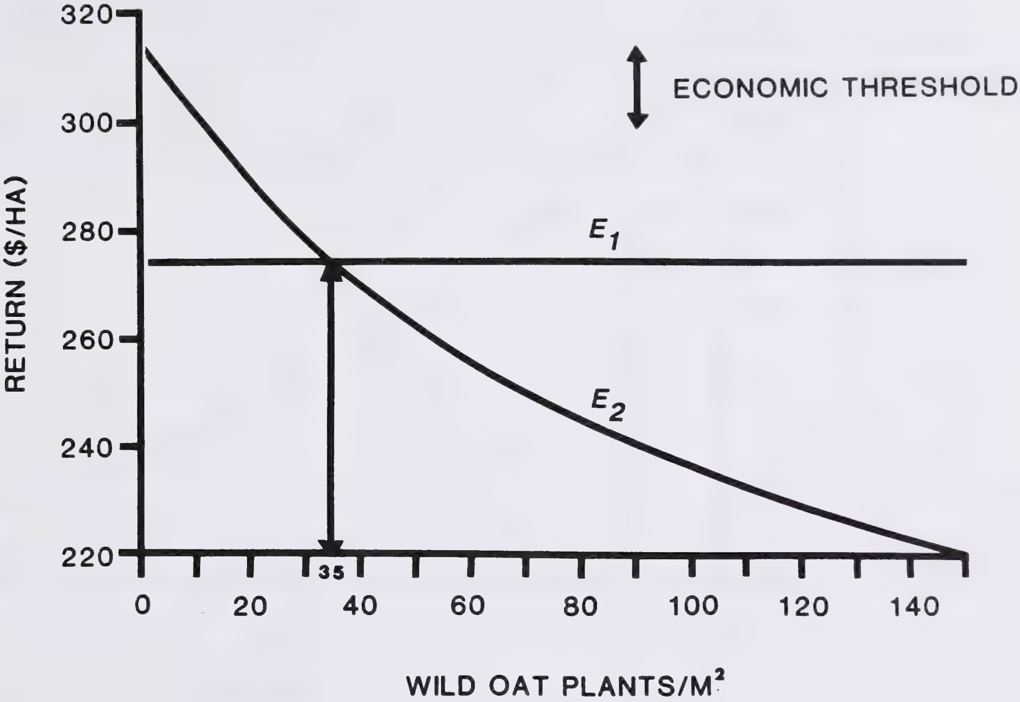

Figure 4. Economics of wild oat control in barley.

Economic thresholds were calculated using combinations of equations 2, 4 and 5 (see text, pages 11 and 12).
E_1 = wild oat was controlled with a herbicide.
E_2 = wild oat was not controlled.
Wild oat free barley yield = 3.5 t/ha.
Barley market price = $90/t.
Herbicide cost = $34/ha.
Herbicide application cost = $7/ha.

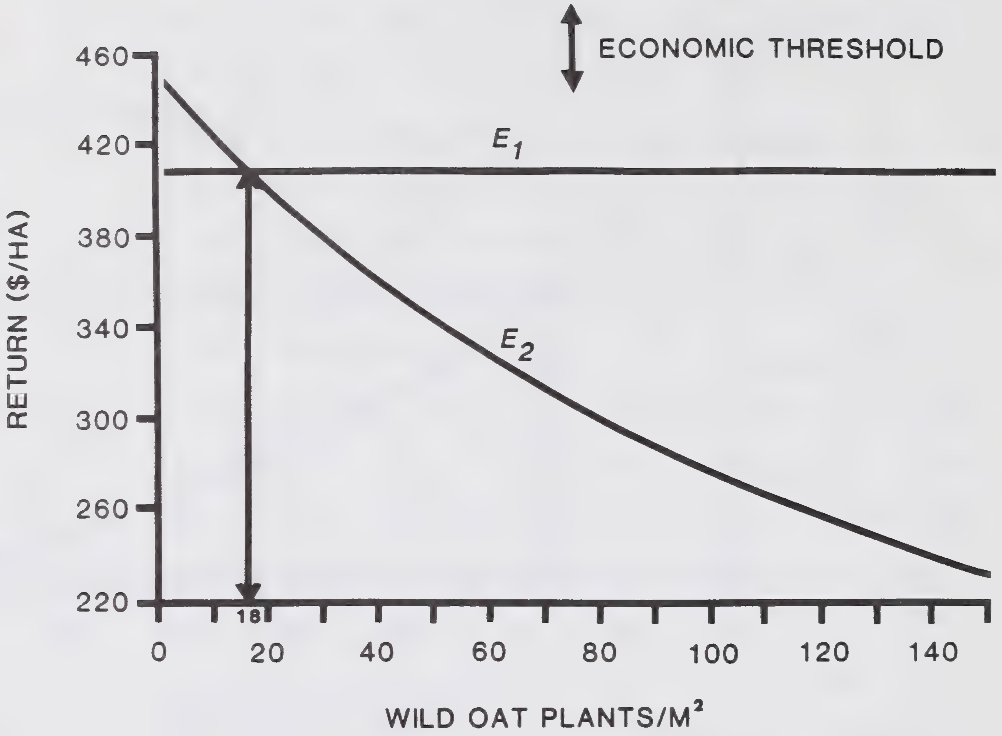

Figure 5. Economics of wild oat control in wheat.

Economic thresholds were calculated using combinations of equations 2, 4 and 5 (see text, pages 11 and 12).
E_1 = wild oat was controlled with a herbicide.
E_2 = wild oat was not controlled.
Wild oat-free wheat yield = 2.5 t/ha.
Wheat market price = $180/t.
Herbicide cost = $34/ha.
Herbicide application cost = $7/ha.

Table 5. Calculated economic thresholds (plants/m^2) for control of wild oat in barley.

Market price of barley ($/t)	Expected wild oat-free volunteer barley yield (t/ha) 2.5	3.5	4.5
	Economic threshold (plants/m^2)		
60	120	62	42
90	55	35	25
120	38	24	18

Table 6. Calculated economic thresholds (plants/m^2) for control of wild oat in wheat.

Market price of wheat ($/t)	Expected wild oat-free wheat yield (t/ha)		
	2.0	2.5	4.5
	Economic threshold (plants/m^2)		
130	31	24	19
180	22	18	12
230	14	12	10

The results of this study show that wild oat can cause severe yield losses in barley and wheat. However, the yield losses caused by a given wild oat density will vary considerably, depending on when the wild oat emerges in relation to the crop. Earlier emerging wild oat will cause greater yield losses. The cost-benefit of controlling wild oat with herbicides will be influenced by factors such as the expected crop yield and crop market prices. Generally, higher canola yields and prices will lower the economic threshold and favour control, while lower yields and prices will have the opposite effect.

A computer program, based on the models developed in this study, has been developed by the Manitoba Department of Agriculture and is available to agricultural representatives and producers in western Canada (M. Goodwin, Manitoba Department of Agriculture, personal communication).

SECTION 2.

INFLUENCE OF VOLUNTEER CEREALS ON YIELD AND PROFITABILITY OF CANOLA

ABSTRACT

The effects of different densities of volunteer barley (*Hordeum vulgare* L.) and volunteer wheat (*Triticum aestivum* L.) on the yield of canola (*Brassica campestris* L. "Tobin" and *B. napus* L. "Westar"), and the seed yield of the volunteer cereals were determined in field experiments conducted at Vegreville and Lacombe, Alberta and Scott, Saskatchewan. Nonlinear hyperbolic models provided a good fit to the data in most instances and indicated that both cereals can severely reduce canola yields with losses increasing with increasing volunteer cereal densities. Canola yield losses were greater when canola densities were relatively low. "Westar" canola appeared less tolerant to volunteer cereal competition than "Tobin" canola. Yield loss predictions from the models were used to determine the economics of volunteer cereal control with herbicides. Generally, higher canola yields and prices lowered the economic threshold and favoured control, while higher yields and prices had the opposite effect. In some cases revenue losses due to reduced canola yield could be alleviated when the value of the volunteer cereal was considered.

INTRODUCTION

In recent years, canola has become an important oilseed crop in western Canada. The most widely grown cultivars are "Tobin" and "Westar". "Westar" outyields "Tobin" by 15-20% under good moisture and frost-free conditions, but "Tobin" is more suitable for most regions of the prairies because of its earlier maturity (Anonymous, 1985). Volunteer barley and wheat are major problems in canola. A lack of herbicides for broad-spectrum control of grasses has prompted the chemical industry to develop herbicides to control volunteer cereals and other grasses. Sethoxydim (Poast®) and fluazifop butyl (Fusilade®) have been registered in Canada and provide excellent control of volunteer cereals (Qureshi and Feddema, 1985; Chow et al., 1983). Several other herbicides for control of grasses are under development and may be registered in the future.

There is little information in the literature on the effects of volunteer cereals on yield loss of canola or on their yield potential when growing in a canola crop. This information could be used to determine when control of volunteer cereals in canola is cost-effective.

The objectives of this study were to determine a) Yield losses of "Tobin" and "Westar" canola due to different densities of volunteer barley and wheat; and b) the economics of controlling volunteer barley and wheat in canola with herbicides. The suitability of a rectangular hyperbolic model in describing the data and the influence of precipitation and temperature during the growing season on canola yield and percentage yield loss were determined.

EXPERIMENTAL DETAILS

Field Operations

Field experiments were conducted at the Agriculture Canada Research Station, Scott, Saskatchewan on a clay loam soil (31% sand, 42% silt, 27% clay, 4% organic matter and pH 6.0) in 1982, 1984, 1985 and 1986; at the Agriculture Canada Research Station Lacombe, Alberta (volunteer barley experiments only), on a sandy loam soil (54% sand, 37% silt, 9% clay, 10% organic matter and pH 5.6) in 1984 and a silt loam soil (26% sand, 34% silt, 40% clay, 9% organic matter and pH 6.0) in 1985; and at the Alberta Environmental Centre, Vegreville on a loam soil (31% sand, 47% silt, 22% clay, 11% organic matter and pH 7.3) in 1985, and a sandy loam soil (60% sand, 28% silt, 12% clay, 6% organic matter and pH 6.6) in 1986. Plots were fertilized each year according to the soil test recommendations for canola. "Tobin" canola was seeded at all locations, while "Westar" was also seeded at Scott (1984 and 1986) and at Lacombe (1984 and 1985). The barley cultivars were "Melvin" (Scott 1982), "Bonanza" (Scott 1984-1986), "Galt" (Lacombe) and "Klondike" (Vegreville). The wheat cultivar at Scott and Vegreville was "Neepawa".

Canola was seeded in rows with double disc press drills at all sites. Seeding rates were 6.7 and 7.8 kg/ha for "Tobin" and "Westar", respectively. Seven target densities of volunteer barley and wheat ranging from 10 to approximately 200 plants/m^2 were packaged and seeded in individual plots. The method of seeding the volunteer cereals varied among locations. At Scott (volunteer barley and wheat) and Lacombe (volunteer barley only) different densities were seeded with double disc press drills between the canola rows and at right-angles to the canola rows, respectively. At Vegreville, volunteer barley and wheat at different densities were hand-spread in the plots and manually raked into the soil. At Lacombe and Vegreville, volunteer cereal plant counts present in the plots shortly after emergence were determined, while at Scott volunteer cereal plants were thinned to desired densities. Each experiment had volunteer cereal-free check plots.

Plot size was 1 by 5 m, 2 by 3 m and 2 by 2 m at Scott, Lacombe and Vegreville, respectively. Areas 4.0 m^2, 1.0 m^2 and 0.5 m^2, respectively, were established in each plot and plant counts (at emergence) and yield of both canola and cereal were taken from these areas. Canola and cereal plants were hand-cut using sickles. To avoid border effects, at least one row of canola around the perimeter of the plots was not harvested. Samples were allowed to dry to constant weights prior to threshing in stationary threshers.

Data Analysis

A randomized complete block design with four replicates was used in all experiments. Pearson correlation coefficients were calculated to determine the influence of precipitation and temperature on canola yield and percentage canola yield loss due to the volunteer cereals. The relationship between canola yield and volunteer cereal density for each year and cultivar at each location, and for data pooled over all experiments was described using a rectangular hyperbolic model suggested by Cousens (1985b):

$$Yc = Ywf \left[1 - \frac{id}{100(1 + id/a)}\right] \qquad (6)$$

where:

Yc = the estimated canola yield (t/ha) as a function of volunteer cereal density,

Ywf = the estimated volunteer cereal-free canola yield (t/ha),

a = the asymptotic canola yield loss as d approaches infinity,

d = the volunteer cereal density (plants/m^2), and

i = the slope or percentage canola yield loss per unit cereal density as d approaches zero.

Canola yield for each plot was also expressed as a percentage of the volunteer cereal-free yield, pooled over all experiments and fitted to the model:

$$Yl = \frac{id}{1 + id/a} \qquad (7)$$

where Yl is the estimated percentage canola yield loss. Other parameters were as described for model (6). This model is similar to model (6), but was rearranged to fit percentage yield loss data rather than absolute yields.

The relationship between volunteer cereal yield and density for each experiment, and for data pooled over all experiments, was described using a model similar to model (7), except that i is the wheat yield per unit wheat density as density approaches zero, and a is the asymptotic wheat yield as density approaches infinity.

Pooled percentage canola yield loss and cereal yield data were also fitted to a three-parameter hyperbolic model described by Cousens (1985a):

$$Yl,\ Yb \text{ or } Yw = \frac{afd}{1 + bc + fd} \tag{8}$$

where:

Yl = estimated percentage canola yield loss,

Yb = volunteer barley yield (t/ha),

Yw = volunteer wheat yield (t/ha),

a = asymptotic percentage canola yield loss or cereal yield,

c = canola density (shoots/m^2),

d = volunteer cereal density (shoots/m^2),

b = nonlinear coefficient for canola density, and

f = nonlinear coefficient for volunteer cereal density.

Pooled percentage canola yield loss data were also fitted to a multiple regression model:

$$Yl = b_0 + b_1\sqrt{d} + b_2 c \tag{9}$$

where:

b_0 = the Yl intercept,

b_1 = the regression coefficient for volunteer cereal (d), and

b_2 = the regression coefficient for canola density (c).

Nonlinear, maximum likelihood iterative procedures from the SAS statistical package were used to fit the data to the hyperbolic models. Data were fitted to the linear regression model using Lotus 1-2-3.

Economic Analysis

The economics of controlling the volunteeer cereal with a herbicide compared to harvesting it as a second crop was determined using the equations:

$$E_1 = (V(1 - L)P_1) - (H + A) \tag{10}$$

$$E_2 = V(1 - L)P_1 \tag{11}$$

$$E_3 = [(V(1 - L)P_1) + WP_2] - S \tag{12}$$

where:

E_1 = cash returns (\$/ha) when the volunteer cereal is controlled with a herbicide,

E_2 = cash returns (\$/ha) when the volunteer cereal is not controlled and considered to have no market value,

E_3 = cash returns (\$/ha) when the volunteer cereal is not controlled and considered to have a market value,

A = the application cost (\$/ha),

H = the herbicide cost (\$/ha),

L = the proportional canola yield loss per unit volunteer cereal density,

P_1 = the market price (\$/t) of canola,

P_2 = the market price (\$/t) of the volunteer cereal,

S = the cost (\$/t) of separating the volunteer cereal and canola seed,

V = the expected volunteer cereal-free canola yield (t/ha), and

W = the estimated volunteer cereal yield (t/ha) as a function of wheat density.

Economic threshold volunteer cereal densities were calculated graphically in Lotus 1-2-3 using combinations of equations (8), (10), (11) and (12).

RESULTS AND DISCUSSION

Volunteer-barley and wheat-free canola yields (*Ywf*) varied significantly among experiments ($P < 0.001$) (Tables 7 and 8, respectively). This was probably due to variable climatic conditions among years and between locations (Table 9). There were strong correlations between canola yield and both precipitation and temperature during July in both volunteer barley and volunteer wheat experiments (Table 10). Higher precipitation and lower temperatures tended to favour higher yields. This may have been related to canola flower and pod development which normally occur during July in western Canada. Ample soil moisture is necessary during canola flowering and pod development (Krogman and Hobbs, 1975), and relatively cool temperatures favour canola growth and development (Warren Wilson, 1966). Correlations between canola yield and climatic conditions during the other months of the growing season were not significant ($P > 0.05$) (Table 10).

Although canola seeding rates were similar for all experiments, canola densities differed significantly ($P < 0.001$) among locations and years. The differences were greatest at Scott where in the volunteer barley experiments canola densities varied from 104 plants/m^2 in 1984 to only 20 plants/m^2 in 1985; while in the volunteer wheat experiments, canola densities varied from an average of 123 plants/m^2 in 1984 to only 12 plants/m^2 in 1985. Since seeding rates were the same in all experiments, variable soil moisture at seeding time may partly account for these differences. In all experiments a nonlinear model (rectangular hyperbola) was used to describe the data since its parameters are more biologically

Table 7. Estimated parameters of the hyperbolic model (standard errors in parentheses) for canola yield as a function of volunteer barley plants/m^2 at emergence †.

Experiment	Canola cultivar	Observed mean weed-free yield	*Ywf*	*i*	*a*	r^2
1982 S	Tobin	2.2	2.1(1.2)	1.21(0.57)	66.31(12.58)	0.68
1984 S	Tobin	1.1	1.1(0.6)	1.26(0.47)	84.59(15.32)	0.77
1985 S	Tobin	0.7	0.7(0.8)	0.82(0.61)	154.71(144.47)	0.47
1986 S	Tobin	1.6	1.6(0.8)	0.38(0.33)	49.53(34.14)	0.42
1984 S	Westar	0.8	0.8(0.9)	1.63(0.51)	97.32(14.12)	0.82
1986 S	Westar	1.8	1.7(1.2)	1.02(0.60)	71.69(20.64)	0.59
1984 L	Tobin	2.1	2.1(0.6)	0.57(0.18)	107.71(56.37)	0.80
1985 L	Tobin	2.1	2.1(1.1)	0.74(0.27)	126.99(54.79)	0.73
1984 L	Westar	2.3	2.2(0.9)	0.76(0.33)	95.21(50.54)	0.73
1985 L	Westar ††	1.8	--------	--------	--------	----
1985 V	Tobin	1.3	1.2(0.8)	0.91(0.38)	104.41(31.26)	0.66
1986 V	Tobin	4.4	4.2(1.5)	1.29(0.24)	117.69(13.67)	0.91
Pooled Model	Tobin and Westar		1.7(0.07)	0.66(0.19)	151.29(67.84)	0.26

† Data were fitted to model (6) (see text, page 35).
†† Parameters could not be estimated due to failure of the equation to converge.
S denotes Scott, L Lacombe and V Vegreville.

Table 8. Estimated parameters of the hyperbolic model (standard errors in parentheses) for canola yield as a function of volunteer wheat plants/m^2 at emergence[†] .

Experiment	Canola cultivar	Observed mean weed-free yield	*Ywf*	*i*	*a*	r^2
1984 S	Tobin	1.0	1.0(30)	0.49(0.12)	220.14(132.50)	0.89
1985 S	Tobin	0.8	0.7(60)	1.16(0.46)	156.31(61.11)	0.74
1986 S	Tobin	1.7	1.7(40)	0.27(0.02)	411.80(924.30)	0.77
1984 S	Westar	0.7	0.7(20)	0.45(0.12)	266.57(273.57)	0.86
1986 S	Westar	2.3	2.3(16)	6.78(3.59)	53.74(5.46)	0.61
1985 V	Tobin	1.5	1.4(15)	2.02(1.25)	84.49(21.28)	0.50
1986 V	Tobin	4.2	3.8(21)	0.94(0.32)	94.86(20.25)	0.72
Pooled Model	Tobin and Westar	1.8	1.7(13)	1.02(0.54)	90.09(29.47)	0.16

[†] Data were fitted to model (6) (see text, page 35).

S denotes Scott, and V Vegreville.

Table 9. Monthly precipitation and mean temperatures at Scott, Lacombe and Vegreville.

		Precipitation (mm)					Mean temperature (c)				
Location	Year	May	June	July	August	Total	May	June	July	August	Average
Scott	1984	40.2	82.1	8.8	41.8	172.9	9.1	14.2	17.7	18.2	14.8
	1985	51.8	10.6	38.2	77.6	178.2	12.0	12.5	17.9	14.8	14.3
	1986	60.0	68.8	98.6	13.9	241.3	11.4	15.2	15.8	16.0	14.6
Lacombe	1984	77.4	57.3	49.2	61.5	245.4	8.6	13.4	15.6	16.6	13.5
	1985	30.4	36.9	62.1	133.3	262.7	11.6	12.6	16.6	12.3	13.3
Vegreville	1985	40.1	86.2	19.5	35.0	180.8	12.1	12.7	16.5	14.1	13.9
	1986	49.0	47.3	118.6	22.0	236.9	11.9	14.8	14.9	15.1	14.2

Table 10. Linear correlation coefficients between estimated volunteer barley and wheat-free canola yields and average precipitation and mean temperatures (May to August). Data were pooled over locations and years.

	Correlation coefficients			
	Barley		Wheat	
Month	Precipitation	Temperature	Precipitation	Temperature
May	0.17	0.13	0.35	0.46
June	0.17	0.30	-0.10	0.53
July	0.71**	-0.80**	0.83*	-0.92**
August	0.02	0.22	-0.62	-0.37
May-August	0.60*	0.33	0.77*	-0.33

*, ** Significant at the 5% and 1% levels, respectively.

meaningful than those of the more widely used linear regression model. The advantages of the hyperbolic model over other models are discussed in detail by Cousens (1985a, b).

Estimating Canola Yield Loss Due to Volunteer Cereals

Estimated parameters of the hyperbolic model for canola yield as a function of volunteer barley and wheat density are presented in Tables 7 and 8, respectively. In all cases the regressions were significant ($P < 0.05$). The model provided a reasonably good fit to the data in most instances (as indicated by the r^2 values). With the exception of the data set for Scott (Tobin) 1985 (volunteer barley experiment), the inclusion of canola density as an extra variable in the hyperbolic model for individual experiments did not significantly improve the fit of the data. Parameters for the hyperbolic model could not be estimated for "Westar" canola at Lacombe in 1985 due to failure of the equation to converge. In other cases, parameter a (maximum percentage yield loss) was poorly estimated as indicated by values over 100. These anomalies resulted mainly because experiments were not designed specifically to fit the hyperbolic model. Cousens (1985a) has indicated that parameter a is highly sensitive to the distribution of weed densities and will tend to be overestimated when the highest densities are not very great. To avoid this, weed densities higher than those which normally occur under field conditions should be used in experiments.

The value of the initial slope (i) which is a measure of the competitiveness of individual volunteer barley and wheat plants differed among some experiments (Tables 7 and 8). For example, in the volunteer barley experiments, the slope for Tobin canola varied from 0.38 for Scott in 1986 to 1.29 for Vegreville in 1986. Some of the variation in volunteer cereal interference probably resulted from variable canola densities, different barley cultivars and methods of seeding the barley, as well as differing soil conditions. However, climatic variability did not appear to account for the differences since yield loss parameters were very poorly correlated with monthly precipitation and temperature.

In most cases, within a location and year, initial slopes for "Westar" were greater than those for "Tobin". This was true for volunteer barley, at Scott in 1984 and 1986, and at Lacombe in 1984 (Table 7). Slopes for the hyperbolic model could not be compared for Lacombe in 1986 due to failure of the "Westar" equation to converge. However, a calculated linear regression coefficient was also higher for "Westar" (0.52) than for "Tobin" (0.42). Although the magnitude of the yield loss due to volunteer wheat was very similar in both cultivars at Scott in 1984, losses were considerably higher for "Westar" than for "Tobin" in 1986 (Table 8). It would appear, therefore, that "Westar" is less competitive than "Tobin", especially at low volunteer cereal densities. Since "Westar" matures later than "Tobin", its slower growth may render it more susceptible to competition from volunteer cereals and other weeds.

Pooling the canola yield data over locations and years resulted in a very poor fit ($r^2 = 0.26$ and 0.16 for volunteer barley and wheat, respectively) (Tables 7 and 8). This was due primarily to the variation in canola yields among experiments. When canola yield was converted to percentage canola yield loss and the data were fitted to model (7), some of the effects of location and year were removed, and the fit was improved considerably. The model was:

$$Yl = \frac{0.85d}{1 + 0.85d/108.7} \qquad r^2 = 0.60$$

for volunteer barley and

$$Yl = \frac{1.19d}{1 + 1.19d/84.48} \qquad r^2 = 0.54$$

for volunteer wheat. Fitting pooled percentage yield loss data to model (8), which incorporated canola density improved the fit further. The model was:

$$Yl = \frac{100\ (0.017d)}{1 + 0.0097c + 0.017d} \qquad r^2 = 0.63$$

for volunteer barley and

$$Yl = \frac{100\ (0.03d)}{1 + 0.04c + 0.03d} \qquad r^2 = 0.62$$

for volunteer wheat. In both equations, regression coefficients for both volunteer cereal and canola density were significant ($P < 0.05$). The pooled model provides an average estimate of percentage canola yield losses over a range of volunteer cereal and canola densities across locations and years. Percentage canola yield loss derived from the model at several canola densities are presented graphically in Figs. 6 (volunteer barley) and 7 (volunteer wheat). At all canola densities, canola yield loss increased with increasing volunteer barley and wheat densities. However, the losses were greater at the lower than at the higher canola densities. Canola density appears to influence the effect of volunteer wheat on canola yield loss more than volunteer barley. In previous studies crop density has also been shown to influence the competitive ability of weeds (Carlson and Hill, 1985; Cousens, 1985a; Hume, 1985).

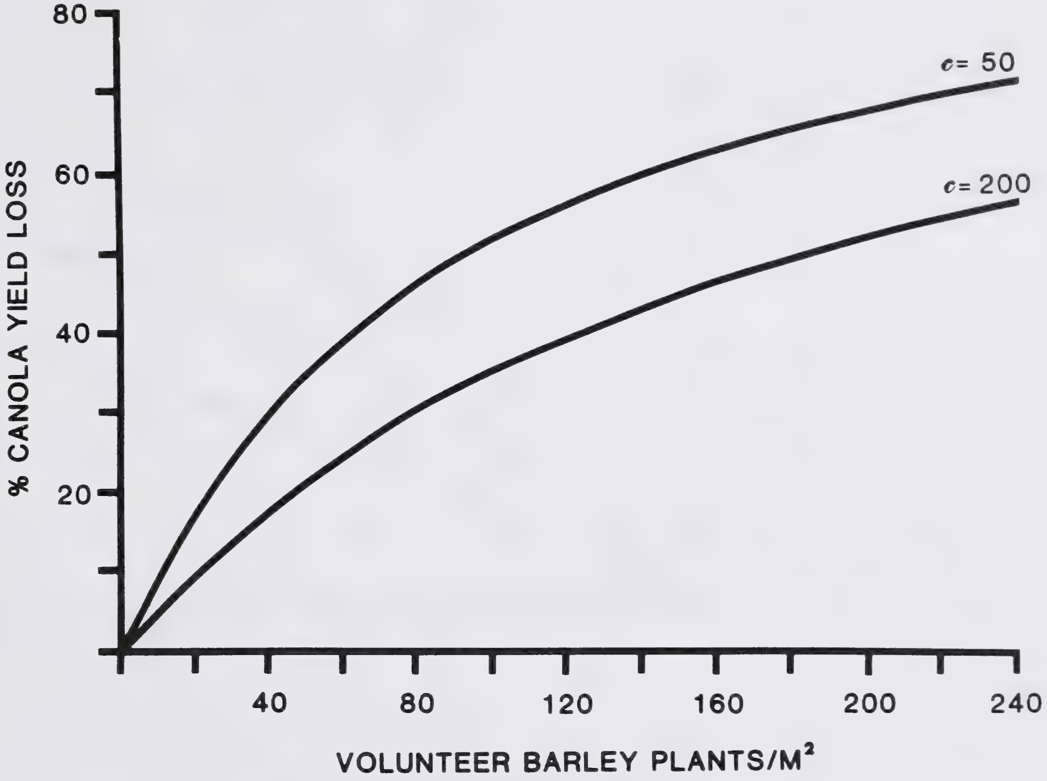

Figure 6. Influence of volunteer barley density on yield loss of canola. Data were fitted to model 8 (see text, page 36). c = canola plants/m^2.

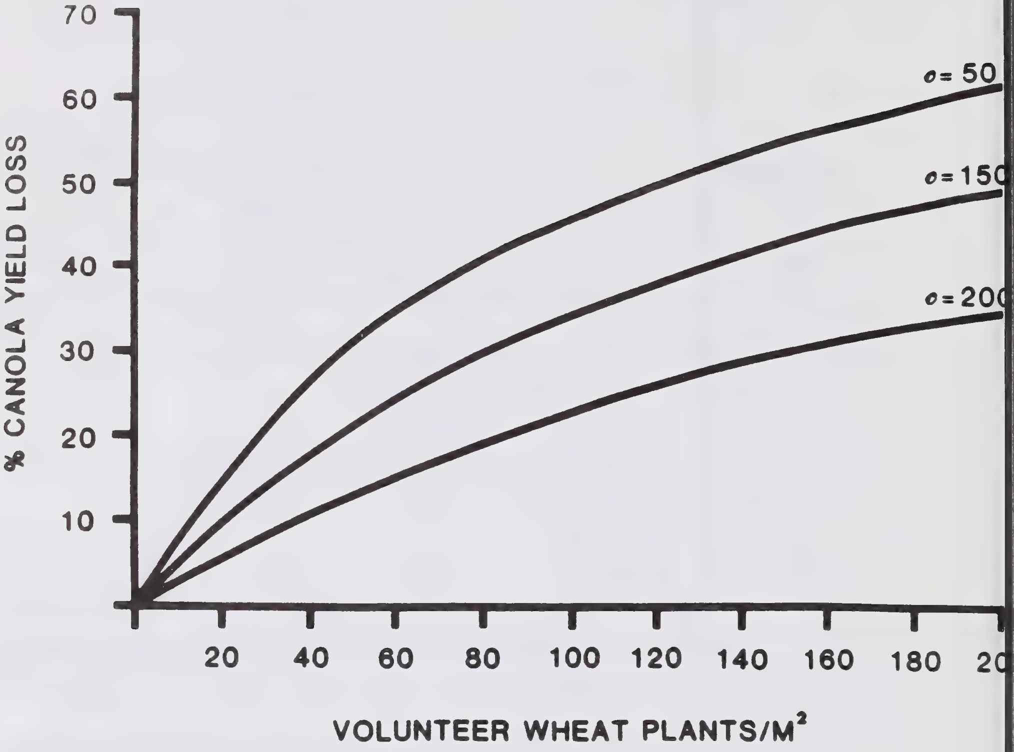

Figure 9. Influence of volunteer wheat density on yield loss of canola. Data were fitted to model 8 (see test, page 36). *c* = canola plants/m^2.

Since most of the models for estimating yield losses due to weeds in western Canada have been developed using linear regression analysis, percentage canola yield loss data were also fitted to a multiple regression model. This enabled the competitiveness of volunteer barley and wheat to be compared with that of other weeds in canola. The model was:

$$Yl = 4.2 + 4.9\ \sqrt{d} - 0.06c \qquad r^2 = 0.63$$

for volunteer barley and,

$$Yl = 14.0 + 4.4\ \sqrt{d} - 0.17c \qquad r^2 = 0.62$$

for volunteer wheat. The regression coefficients for volunteer barley (4.9) and wheat (4.4) compare to previously reported regression coefficients of 3.2, and 10.4 for wild oat (Dew and Keys, 1976) and Canada thistle (O'Sullivan et al., 1985), respectively, in canola. This suggests that volunteer barley and wheat are more competitive than wild oat, but considerably less competitive than Canada thistle.

Although the multiple regression model provided as good a fit to the data as the nonlinear hyperbolic model, the presence of the intercept can result in overestimation of canola yield losses at low volunteer cereal densities, especially with volunteer wheat where the intercept was relatively large. The multiple regression model also predicts a yield loss or gain when no volunteer cereal is present, and a yield loss approaching infinity at high volunteer cereal densities. The hyperbolic model, on the other hand, passes through the origin and reaches an asymptotic upper limit as volunteer cereal densities increase (Figs. 6 and 7). It is therefore more biologically sound than the multiple regression model.

Estimating Volunteer Cereal Yield

Volunteer barley and wheat differ from weeds in that the seed may have a potential market value. An estimate of seed yield at different infestations of the volunteer cereals would be useful when determining the cost-benefit of herbicide application. The barley cultivars used in this study were medium maturing cultivars (90-95 days). They mature about the same time as "Tobin" canola and about 10 to 21 days before "Westar" which matures close to the time of "Neepawa" wheat. Estimated parameters of the hyperbolic model for volunteer barley yield as a function of barley density, and volunteer wheat yield as a function of wheat density are presented for individual experiments in tables 11 and 12, respectively. In most cases the model provided a very good fit to the data. Parameters were not estimated for "Westar" canola at Scott (volunteer barley experiment) in 1986 due to failure of the equation to converge. This was probably due to reasons previously discussed (page 44). The values of the slope (i) which are estimates of the seed yield of individual barley and wheat plants, varied among experiments, probably due to variable canola densities, different barley cultivars and differing soil and climatic conditions.

Pooling the data over locations and years gave a poorer description of the data (r^2 = 0.48 and 0.69 for volunteer barley and wheat, respectively) than did the model fitted to individual experiments. This was probably due to variable volunteer barley and wheat yields, and canola densities among experiments. Fitting the pooled data for each volunteer cereal to model (8) (with canola density as an extra parameter) resulted in the model:

Table 11. Estimated parameters of the hyperbolic model (standard errors in parentheses) for volunteer barley yield as a function of volunteer barley density (plants/m^2) at emergence†.

Experiment	Canola Cultivar	*i*	*a*	r^2
1982 S	Tobin	0.10(0.01)	6.2(0.53)	0.91
1984 S	Tobin	0.02(0.004)	2.1(0.43)	0.82
1985 S	Tobin	0.04(0.005)	2.0(0.15)	0.43
1986 S	Tobin	0.04(0.006)	4.2(0.52)	0.91
1984 S	Westar	0.03(0.007)	1.9(0.21)	0.84
1986 S	Westar ††	....	....	....
1984 L	Tobin	0.02(0.002)	8.3(0.39)	0.93
1985 L	Tobin	0.03(0.004)	9.5(0.55)	0.94
1984 L	Westar	0.02(0.002)	4.8(0.76)	0.91
1985 L	Westar	0.03(0.004)	8.4(0.35)	0.90
1985 V	Tobin	0.04(0.001)	2.1(0.30)	0.69
1986 V	Tobin	0.10(0.001)	8.7(0.75)	0.93
Pooled Model	Tobin & Westar	0.03(0.00005)	4.5(0.008)	0.48

† Data were fitted to model 7 (see text, page 35).

†† Parameters could not be estimated due to failure of the equation to converge.

S denotes Scott, L Lacombe and V Vegreville.

Table 12. Estimated parameters of the hyperbolic model (standard errors in parentheses) for volunteer wheat yield as a function of volunteer wheat density (plants/m^2) at emergence †.

Experiment	Canola Cultivar	i	a	r^2
1984 S	Tobin	0.09(0.001)	2.5(0.50)	0.96
1985 S	Tobin	0.04(0.005)	2.1(0.17)	0.91
1986 S	Tobin	0.08(0.002)	4.5(0.34)	0.83
1984 S	Westar	0.02(0.001)	2.7(0.39)	0.96
1986 S	Westar	0.02(0.005)	1.8(0.27)	0.82
1985 V	Tobin	0.03(0.005)	2.0(0.28)	0.83
1986 V	Tobin	0.02(0.002)	7.5(0.18)	0.93
Pooled Model	Tobin & Westar	0.02(0.001)	3.5(0.60)	0.69

† Data were fitted to model 7 (see text, page 35).

S denotes Scott, and V Vegreville.

$$Yb = \frac{3.8\ (0.015d)}{1 + 0.007c + 0.015d} \qquad r^2 = 0.49$$

for volunteer barley and

$$Yw = \frac{2.8\ (0.012d)}{1 + 0.018c + 0.012d} \qquad r^2 = 0.76$$

for volunteer wheat. Inclusion of canola density in the model improved the fit in the case of volunteer wheat but not in the case of volunteer barley. However, in both cases the regression coefficients for canola density were highly significant ($P < 0.01$) indicating that canola density influenced the extent of the canola yield loss caused by volunteer barley and wheat. The relationships between volunteer cereal densities and yields at different canola densities are presented graphically in Figs. 8 and 9. Yields of volunteer barley and wheat increased with increasing volunteer barley and wheat densities. The responses were almost linear at the lower volunteer cereal densities, but at higher densities the contribution of individual cereal plants to the yield gradually diminished, probably due to increased intraspecific competition. Volunteer cereal yields were higher at the lower canola densities, and the influence of canola density was more pronounced with volunteer wheat than with volunteer barley.

Cost Analysis of Volunteer Cereal Control

The canola yield loss and volunteer cereal yield models developed in this study should be used as guides when the economics of controlling volunteer cereals in canola is being assessed. Estimations from the models, together with information on herbicide and application costs, separation costs and barley, wheat and canola market prices, provide a means of predicting the economic threshold volunteer cereal density.

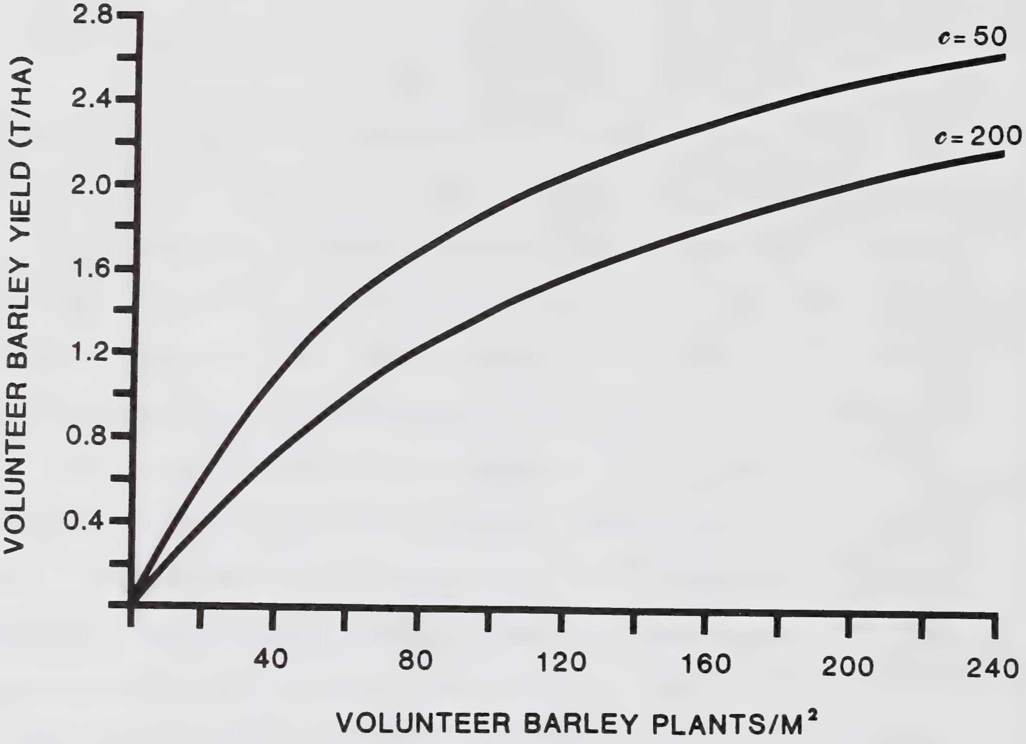

Figure 8. Influence of volunteer barley density on volunteer barley yield. Date were fitted to model 8 (see text, page 36). c = canola plants/m^2.

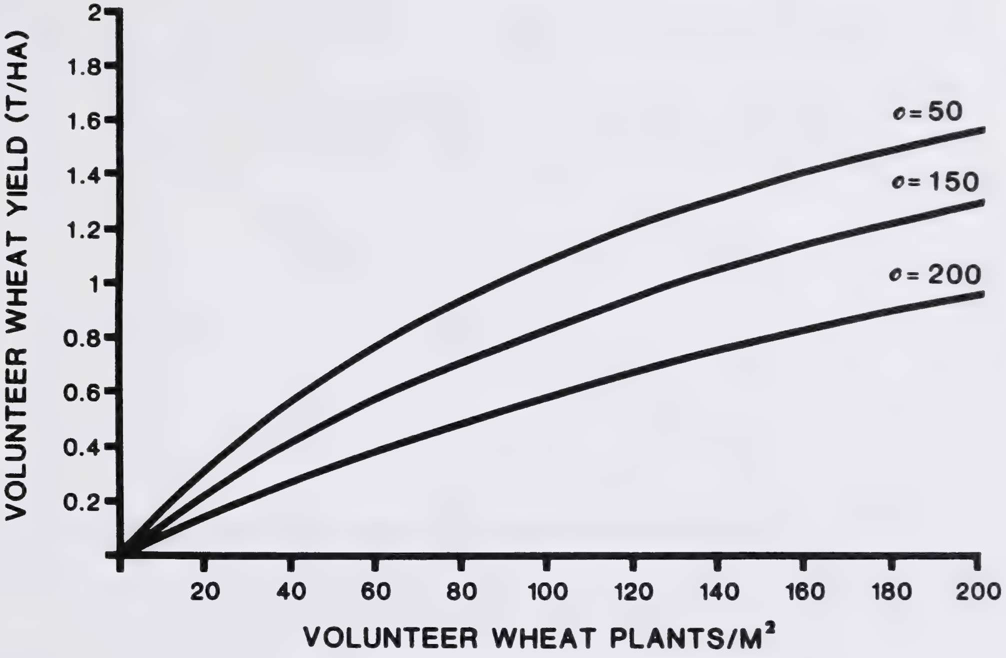

Figure 7. Influence of volunteer wheat density on volunteer wheat yield. Data were fitted to model 8 (see text, page 36). c = canola plants/m^2.

The relationship between controlling the volunteer cereal with a herbicide (E_1), not controlling it but considering it to have no market value (E_2), and not controlling it but considering it to have a market value (E_3) is presented in Figs. 10 and 11 for volunteer barley and wheat, respectively. The assumptions are:

Market price of canola = \$270/t,
Market price of feed barley = \$90/t,
Market price of feed wheat = \$110/t,
Expected volunteer cereal-free canola yield = 1.5 t/ha,
Herbicide cost = \$33/ha,
Herbicide application cost = \$7/ha,
Seed separation cost = \$10/t,

It is also assumed that the canola density was 100 plants/m^2 and that after herbicide application, all of the potential canola yield could be recovered. This may not always be the case, however, especially where spraying is delayed, and/or volunteer cereal densities are heavy.

The economics of controlling the volunteer barley or wheat with a herbicide as indicated by the economic threshold varied considerably depending on whether or not a market value was assigned to the volunteer cereal seed yield (Figs. 10 and 11). If the cereal was considered to have no market value, revenue declined sharply with increasing volunteer cereal densities and spraying was justified at 13 volunteer barley and 19 volunteer wheat plants/m^2, respectively. However, if the cereal was considered to have a value, and separation costs were included, the decline in revenue was less sharp, and the economic threshold increased to 50 volunteer barley and 30 volunteer wheat plants/m^2.

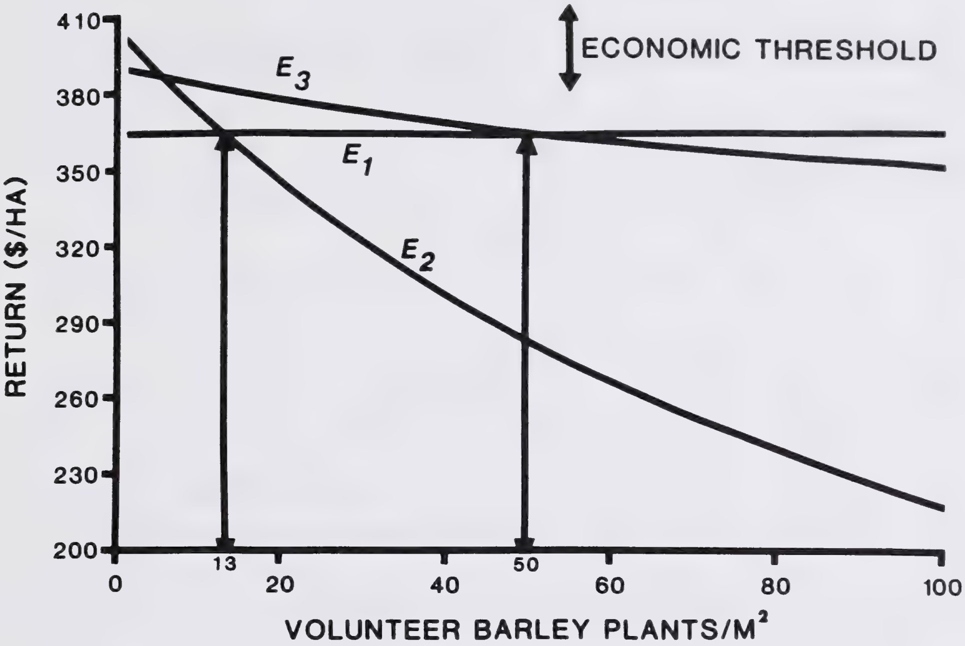

Figure 10. Economics of volunteer barley control in canola.

Economic thresholds were calculated using combinations of equations 8, 10, 11 and 12 (see text, pages 36 and 37).
E_1 = Volunteer barley was controlled with a herbicide.
E_2 = Volunteer barley was not controlled and considered to have no market value.
E_3 = Volunteer barley was not controlled but considered to have a market value.
Volunteer barley-free canola yield = 1.5 t/ha.
Canola market price = $270/t.
Feed barley market price = $90/t.
Seed separation cost = $10/t.
Herbicide cost = $33/ha.
Herbicide application cost = $7/ha.

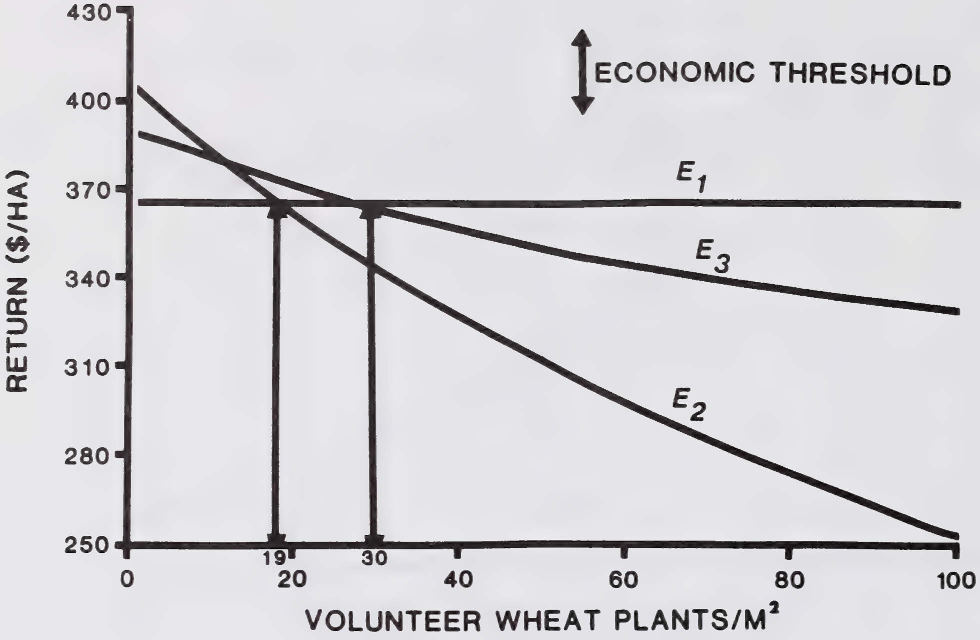

Figure 11. Economics of volunteer wheat control in canola.

Economic thresholds were calculated using combinations of equations 8, 10, 11 and 12 (see text, pages 36 and 37).
E_1 = Volunteer wheat was controlled with a herbicide.
E_2 = Volunteer wheat was not controlled and considered to have no market value.
E_3 = Volunteer wheat was not controlled but considered to have a market value.
Volunteer wheat-free canola yield = 1.5 t/ha.
Canola market price = $270/t.
Feed wheat market price = $110/t.
Seed separation cost = $10/t.
Herbicide cost = $33/ha.
Herbicide application cost = $7/ha.

Economic threshold volunteer cereal densities at several different canola and cereal prices, and canola yields are presented in Tables 13 and 14. It is assumed that herbicide and application costs and seed separation costs remained constant. Where the value of the cereal yield was not considered in the analysis (Assumption A, Tables 13 and 14) the economic threshold values decreased as canola yields and prices increased, especially where expected canola yields were low. When the value of the cereal yield was considered in the analysis (Assumption B, Tables 13 and 14), economic thresholds varied considerably depending on the expected volunteer cereal-free canola yield. At an expected canola yield of 1.0 t/ha, economic thresholds were greater than 500 plants/m^2 indicating that control of the volunteer cereals was not economical at any of the assumed crop prices. At a canola yield of 1.5 t/ha, economic thresholds increased with increasing canola price and were always greater than those where the volunteer cereal was considered to have no market value (Tables 13 and 14). At 2 t/ha, economic thresholds differed little regardless of canola or cereal prices, or whether or not the volunteer cereal was considered to have a market value. In this situation it would be more economical to either control the volunteer cereal with a herbicide (than harvest it as a second crop), or not control it and discard the seed, depending on the volunteer cereal density.

This study shows that volunteer cereals can cause severe yield losses in canola. However, the economics of controlling the volunteer cereal with herbicides will depend on the expected canola yield and crop market prices. Generally, higher canola yields and prices will lower the economic threshold and favour control, while lower yields and prices will have the

Table 13. Calculated economic thresholds (plants/m^2) for control of volunteer barley in canola.

Crop market prices ($/t)		Expected volunteer barley-free canola yield (t/ha)					
		1.0		1.5		2.0	
		Economic thresholds (plants/m^2) †					
Canola	Barley	A	B	A	B	A	B
220	60	26	>500	16	30	12	11
270	90	20	>500	13	50	9	10
320	120	16	>500	11	160	7	15

† Assumption A: The volunteer barley had no market value and was not included in the analysis.

Assumption B: The volunteer barley had a market value which was included in the analysis together with seed separation costs.

Table 14. Calculated economic thresholds (plants/m^2) for control of volunteer wheat in canola.

Crop market prices ($/t)		Expected volunteer wheat-free canola yield (t/ha)					
		1.0		1.5		2.0	
		Economic thresholds (plants/m^2) †					
Canola	Wheat	A	B	A	B	A	B
220	80	36	>500	21	33	16	13
270	110	31	>500	19	30	13	11
320	140	26	>500	15	65	11	10

† Assumption A: The volunteer wheat had no market value and was not included in the analysis.

Assumption B: The volunteer wheat had a market value which was included in the analysis together with seed separation costs.

opposite effect. In some cases, financial losses due to reduced canola yield may be alleviated when the value of the volunteer cereal is considered. This is most likely to be true where canola yields and prices are relatively low.

SECTION 3.

INFLUENCE OF QUACK GRASS ON YIELD AND PROFITABILITY OF CANOLA

ABSTRACT

The effects of different shoot densities of a natural infestation of quack grass (*Agropyron repens* [L]. Beauv.) on the yield of canola (*Brassica campestris* L.) was determined in four field experiments conducted near Vegreville in 1986 and 1988. A nonlinear hyperbolic model provided a good fit to the data and indicated severe canola yield losses due to quack grass, particularly at high shoot densities. Economic thresholds for controlling quack grass with a herbicide varied from 16 to 55 quack grass shoots/m^2, depending on canola market prices and expected yields. Generally, economic thresholds increased as canola yields and prices decreased.

Introduction

Quack grass is a serious perennial grass weed of cultivated land throughout most of Canada (Werner and Rioux, 1977). Because of its perennial nature, the weed can be difficult and expensive to control with herbicides. The non-selective herbicide, glyphosate, can provide effective control of quack grass prior to seeding field crops in the spring, or in the fall after harvest. Two other herbicides, sethoxydim and the butyl ester of fluazifop, are registered for selective control of quack grass in canola while registration is pending on several other herbicides for quack grass control. The cost of currently registered herbicides can range from $35 to $100/ha.

In view of the relatively high cost of controlling quack grass with herbicides, there is surprisingly little information available on the extent of crop yield losses due to quack grass in crops commonly grown in Canada. Rioux (1982) found that an increase of 10 shoots/m^2 in the mean density of quack grass resulted in a 60 kg/ha loss in barley yield. However, there is no information available on canola yield losses due to quack grass.

The objectives of this study were to determine a) the effects of different shoot densities of quack grass on yield of canola; and b) the cost-effectiveness of controlling quack grass in canola with a herbicide.

EXPERIMENTAL DETAILS

Field Operations

Experiments were conducted in four farm fields that had natural infestations of quack grass; two in 1986 and two in 1988. "Tobin" canola was seeded in rows at all locations by the farmers. The fields will be referred to as 1986 A and B, and 1988 A and B.

All soil types were sandy loams with 71% sand, 14% clay, 17% silt, 4.2% organic matter, and pH 8.4 (1986 A); 62% sand, 16% clay, 23% silt, 7.5% organic matter, and pH 7.8 (1986 B); 63% sand, 17% clay, 20% silt, 10.3% organic matter, and pH 7.4, (1988 A); and 63% sand, 15% clay, 22% silt, 3.7% organic matter and pH 6.3, (1988 B).

Canola yields were determined at 7 (0, 1-10, 11-50, 51-100, 101-150, 151-200 and 201-300) (1986 A, B; 1988 B) and 10 (0, 1-10, 11-50, 51-100, 101-150, 151-200, 201-250, 251-300, 301-400 and 401-500) (1988 A) target infestations (shoots/m^2) of quack grass. The different quack grass densities were obtained by selecting and marking 0.5 m^2 areas starting from the outer edge of a quack grass patch (low density) and moving towards the centre (high density). All data were taken from these squares. Each target density had four replicates. The quack grass patch was approached from a different direction for each replicate. In all experiments, quack grass shoots and canola seedlings were counted approximately two weeks after emergence of the crop.

Data Analysis

The relationship between canola yield and quack grass density for each experiment, and for data pooled over all experiments was described using model (6). Canola yield for each plot was expressed as a percentage of the quack grass-free yield, pooled over all experiments and fitted to models (7) and (8). Pooled percentage canola yield loss data were also fitted to a linear regression model

$$YI = b_0 + b_1 \quad d \tag{13}$$

where:

b_0 = the YI intercept, and

b_1 = the regression coefficient for quack grass density.

In both hyperbolic and linear regression models,

d = quack grass density (plants/m^2).

Data were fitted to the nonlinear and linear models using maximum likelihood iterative procedures from the SAS statistical package, and Lotus 1-2-3, respectively.

Economic Analysis

The economics of controlling quack grass with a herbicide was determined using models (4) and (5). Economic threshold quack grass densities were calculated graphically in Lotus 1-2-3 using combinations of models (4), (5) and (7).

RESULTS AND DISCUSSION

Estimating Canola Yield Loss Due to Quack Grass

Estimated parameters of the hyperbolic model for canola yield as a function of quack grass density are presented in Table 15. In all experiments the equations were highly significant ($p < 0.001$), and the model provided a good fit to the data. The magnitude of the predicted yield losses were very similar among experiments (Fig. 12) even though the quack grass-free yields varied (Table 15). This suggests that canola losses due to quack grass may be independant of the expected quack grass-free canola yields. Dew (1972) similarly found that crop yield losses due to wild oat were independent of the crop yields.

In all experiments, parameter *a* (asymptote) was overestimated (Table 15). This was most evident in 1986 suggesting that the relationship between canola yield loss and quack grass density was mainly linear over the range of densities tested (0-218 and 0-196 in fields A and B, respectively). In 1988, the quack grass density ranges were considerably higher (0-411 and 0-626 in fields A and B, respectively), resulting in a more curvilinear relationship with asymptote values closer to 100%. These results suggest that little intraspecific competition occurs among quack grass shoots until densities exceed 120 shoots/m^2 (Fig. 12).

Pooling canola yield data over locations and years resulted in a relatively poor fit ($r^2 = 0.55$) (Table 15), probably due to the variation in canola yield among experiments. However, when canola yield was

Table 15. Estimated parameters of the hyperbolic model (standard errors in parentheses) for canola yield as a function of quack grass shoots/m^2 at emergence †.

		Canola yield (t/ha)				
Year	Field	Observed mean weed-free yield	*Ywf*	*i*	*a*	r^2
1986	A	1.73	2.11(0.12)	0.28(0.14)	1113(11847)	0.62
1986	B	1.29	1.61(0.11	0.36(0.15)	1154(7742)	0.64
1988	A	1.12	1.22(0.09)	0.48(0.21)	135(53)	0.70
1988	B	2.15	2.20(0.13)	0.51(0.15)	121(21)	0.78
Pooled model		1.57	1.79(0.08)	0.45(0.11)	130(27)	0.55

† Data were fitted to model 7 (see text, page 35).

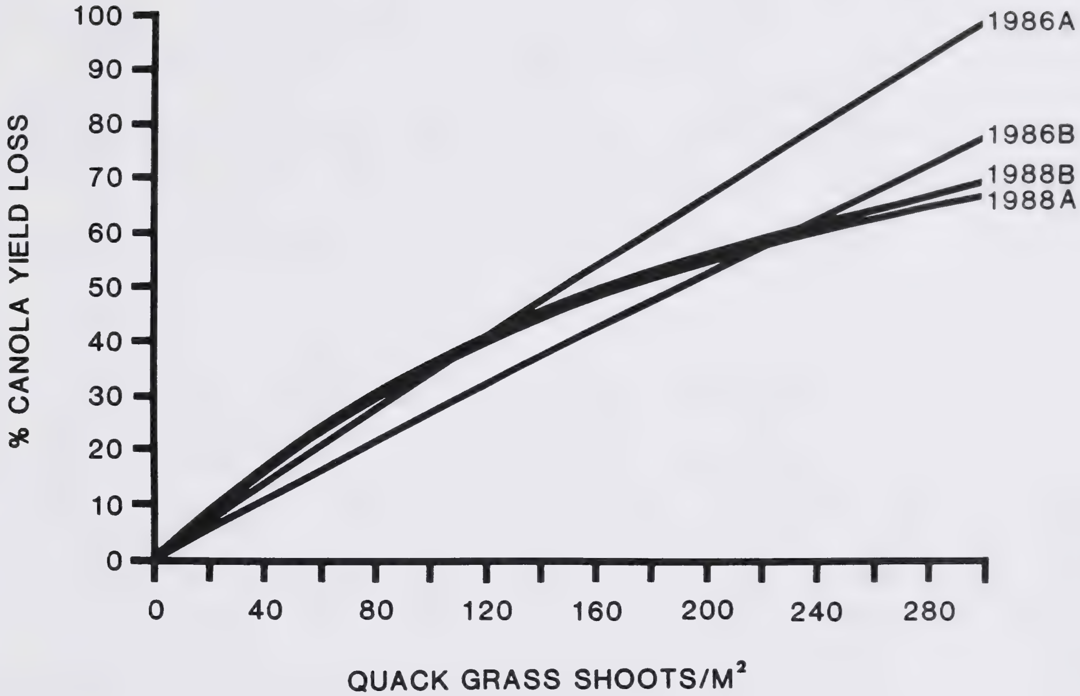

Figure 12. Influence of quack grass density on percentage canola yield loss in four field experiments.

Data were fitted to model 7 (see text, page 35).

converted to percentage canola yield loss, and the data fitted to model (7), some of the effects of location and year were removed, and the fit was improved. The model was

$$Yl = \frac{0.41d}{1 + 0.41d/141} \qquad r^2 = 0.66$$

A graphical representation of the pooled model is presented in Fig. 13. It indicates a curvilinear relationship between percentage canola yield loss and quack grass density with yield loss increasing with increasing quack grass density.

Fitting the data to model (8) and including canola density as an extra variable had little effect on the fit of the equations. Average canola densities per plot were 106 (1986 A), 132 (1986 B), 84 (1988 A) and 115 (1988 B) plants/m^2.

The quack grass density data were also transformed to square roots, and the data fitted to a linear regression model with the regression line constrained to pass through the origin. The model was:

$$Yl = 3.5 \sqrt{d} \qquad r^2 = 0.62.$$

Comparing the regression coefficient (3.5) to a reported regression coefficient of 3.2 for wild oat in canola (Dew and Keys, 1976) indicates that a quack grass shoot is at least as competitive with canola as a wild oat shoot. This is surprising in view of the fact that wild oat shoots generally grow taller and more vigorously than quack grass shoots. The severe effects of quack grass on canola yield, in the present study, may have resulted from early emergence of the quack grass shoots relative to the canola seedlings in that most quack grass shoots emerged from three to seven days before the canola.

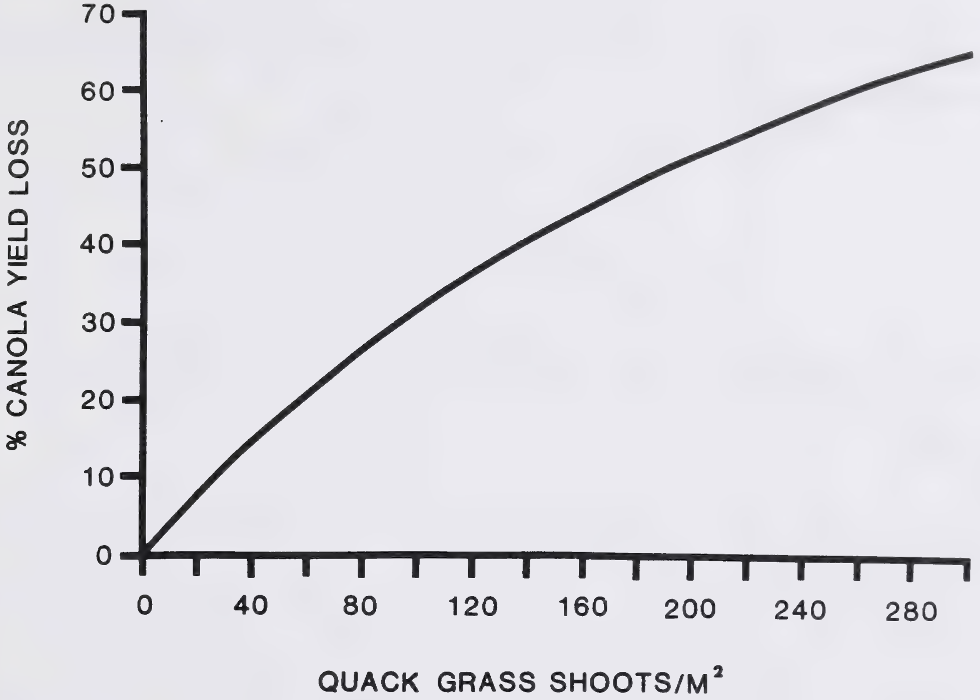

Figure 13. Influence of quack grass density on percentage canola yield loss.

Data were pooled over locations and years and fitted to model 7 (see text, page 35).

Cost Analysis of Quack Grass Control

The relationship between controlling quack grass with a herbicide and not controlling it is presented graphically in Fig. 14. The assumptions are:

Market price of canola = $220/t,
Expected Quack grass-free canola yield = 1.5 t/ha,
Herbicide cost = $36/ha,
Herbicide application cost = $7/ha.

At these prices and costs the economic threshold for quack grass control in canola was 35 shoots/m^2.

Economic threshold densities of quack grass at different canola yields and prices are presented in Table 16. The threshold varied from 16 to 55 quack grass shoots/m^2 depending on expected canola yields and prices. Generally, the economic thresholds decreased as canola yield and price increased.

The results of this study indicate that quack grass can severely reduce canola yields, particularly if the shoots emerge ahead of the canola seedlings. The relatively low economic thresholds indicate that control of quack grass with a herbicide may be generally cost-effective.

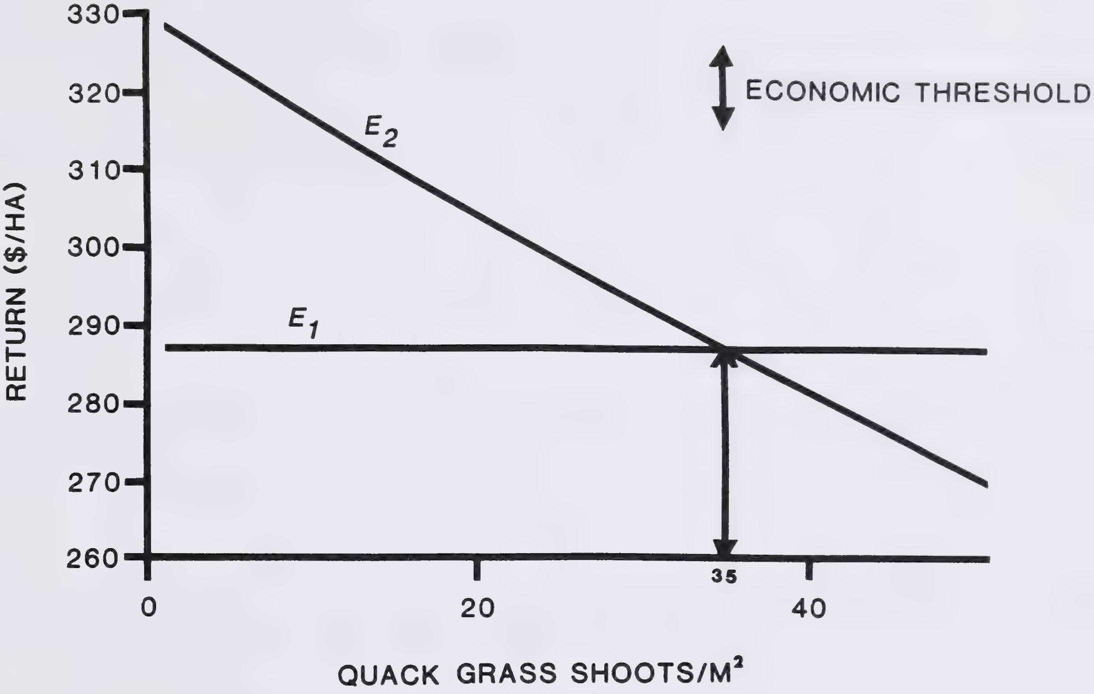

Figure 14. Economics of quack grass control in canola.

Economic thresholds were calculated using combinations of equations 7, 10, and 11 (see text, pages 35 and 37).
E_1 = Quack grass was controlled with a herbicide.
E_2 = Quack grass was not controlled.
Quack grass-free canola yield = 1.5 t/ha.
Canola market price = $220/t.
Herbicide cost = $36/ha.
Herbicide application cost = $7/ha.

Table 16. Calculated economic thresholds (shoots/m^2) for control of quack grass in canola.

	Expected quackgrass-free canola yield (t/ha)		
Market price of canola ($/t)	1.0	1.5	2.0
	Economic thresholds (shoots/m^2)		
220	55	35	25
270	43	27	21
320	36	22	16

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APPENDIX

LIST OF PUBLICATIONS RESULTING FROM THIS WORK

Refereed Journal Publications

1. O'Donovan, J.T., de St. Remy, E.A., O'Sullivan, P.A., Dew, D.A. and Sharma, A.K. 1985. Influence of the relative time of emergence of wild oat on yield loss of barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*). Weed Sci. 33:498-503.
2. Cousens, R., Brain, P., O'Donovan, J.T. and O'Sullivan, P.A. 1987. The use of biologically realistic equations to describe the effects of weed density and relative time of emergence on crop yield. Weed Sci. 35:720-725.
3. O'Donovan, J.T., Sharma, A.K., Kirkland, K.J. and de St. Remy, E.A. 1988. Volunteer barley (*Hordeum vulgare*) interference in canola (*Brassica campestris* and *B. napus*). Weed Sci. 36:734-739.
4. O'Donovan, J.T. 1988. Wild oat infestations and economic returns as influenced by frequency of control. Weed Tech. 2:495-498.
5. O'Donovan, J.T., Kirkland, K.J. and Sharma, A.K. 1989. Canola yield and profitability as influenced by volunteer wheat infestations. Can. J. Plant Sci. 69:1235-1244.
6. O'Donovan, J.T. 1991. Quackgrass (*Elytrigia repens*) interference in canola. Weed Sci. 39:397-401.

Conference Proceedings

1. O'Donovan, J.T. and Sharma, M.P. 1983. Wild oats, competition and crop losses. p. 27-37 *in* Wild Oat Action Comm. Proc., Regina, Saskatchewan. 200 pp.

2. O'Donovan, J.T., Sharma, A.K., Kirkland, K.J. and de St. Remy, E.A. 1987. The effects of volunteer barley on yield and profitability of rapeseed in western Canada. P. 1035-1041 In Proc. British Crop Protection. Conf. - Weeds, Vol. 3, Brighton, U.K. 1128 pp.

Abstracts and Short Communications

1. O'Donovan, J.T. 1983. Influence of time of emergence of wild oats relative to barley and wheat on yield of barley and wheat. Res. Rep. Expert Comm. on Weeds (West. Can. Sect.), p. 279-280.
2. O'Donovan, J.T., de St. Remy, E.A. and O'Sullivan, P.A. 1985. Yield loss of barley and wheat as influenced by the relative time of emergence of wild oat. Proc. Weed Sci. Soc. of America, p. 51.
3. O'Donovan, J.T. 1985. Influence of various densities of volunteer wheat on yield of canola. Res. Rep. Expert Comm. on Weeds (West. Can. Sect.), p. 209-210.
4. O'Donovan, J.T. 1985. Influence of various densities of volunteer barley on yield of canola. Res. Rep. Expert Comm. on Weeds (West. Can. Sect.), p. 210-211.
5. O'Donovan, J.T. 1986. Volunteer barley in canola - a crop or a weed? Minutes, Expert Comm. on Weeds Meeting (West. Can. Sect.), Saskatoon, Saskatchewan, p. 21.
6. O'Donovan, J.T. 1986. Influence of various densities of volunteer wheat on yield of canola. Res. Rep. Expert Comm. on Weeds (West. Can. Sect.), p. 181-182.

7. O'Donovan, J.T. 1986. Influence of various densities of volunteer barley on yield of canola. Res. Rep. Expert Comm. on Weeds (West. Can. Sect.), p. 182.

8. O'Donovan, J.T. 1986. Influence of various densities of quack grass on yield of canola. Res. Rep. Expert Comm. on Weeds (West. Can. Sect.), p. 183-184.

9. O'Donovan, J.T. 1987. Modelling approaches to crop loss assessment. Minutes, Expert Comm. on Weeds Meeting (West. Can. Sect.), Victoria, BC. p. 27-28.

10. O'Donovan, J.T. 1988. Influence of various densities of quack grass on yield of canola. Res. Rep. Expert Comm. on Weeds (West. Can. Sect.), p. 186.

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