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Effect of aqueous extracts of crop residues on germination and seedling growth of ten weed species

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Abstract. Detrimental effects of residues from crops such as canola and lentils on subsequent crops have been observed in petri-dish bioassays and in the field. Suppression of wheat growth by canola and lentil residues has occurred, in producer fields, primarily in the area behind the combine where the residues are concentrated. Adequate straw spreading has permitted producers to grow wheat following canola and lentil crops. The effect of these and other crop residues on common weeds in western Canada has not been assessed. Aqueous extracts of the residues of six different crops were bioassayed for their effect on the germination and seedling growth of ten weeds common in western Canada. Extracts of lentil (*Lens culinaris* Medic), oat (*Avena sativa* L.), canola (*Brassica napus* L.), and barley (*Hordeum vulgare* L.) were more toxic to flixweed (*Descurainia sophia* L. Webb), stinkweed (*Thlaspi arvense* L.), and downy brome (*Bromus tectorum* L.) than extract of canola was to wheat. The greater toxicity of these crop residues to flixweed, stinkweed, and downy brome than to wheat may permit selective management of these weeds in wheat. Flixweed, stinkweed, and downy brome are major winter annual weeds in winter wheat and usually require late fall or early spring herbicide treatments in no-tillage systems. Therefore, residues of canola, lentil, oat and barley have potential for reducing herbicide use in winter wheat production and in no-tillage direct seeding farming systems. Crop extracts were not toxic enough to affect the growth in the field of seven other weeds in this study.

Keywords: Allelochemical activity; Allelopathy; *Bromus tectorium*; Canola; *Descurainia sophia*; Lentil; Oat; *Thlaspi arvense*.

Introduction

Since the late 1940s producers of agricultural crops have increasingly relied on herbicides for weed control. Problems associated with intensive herbicide use include soil and groundwater contamination, development of herbicide resistant weeds, and the escalating cost of developing new herbicides (Worsham, 1989). Recent assessments of the allelopathic effect of crops or crop residues on weeds has the goal of using naturally produced allelochemicals to reduce reliance on herbicides (Einhellig and Leather, 1988; Putnam and Duke, 1974; Putnam and Duke, 1978).

In the semi-arid plains of western Canada, cereal, oilseed, and pulses are the main annual crops grown. Cultivation techniques that maintain a large percentage of the crop residue on the soil surface to prevent soil erosion by wind have been widely adopted (Moyer et al., 1994). There is a trend in recent years toward zero- or minimum-tillage direct seeding cropping systems that leave nearly all crop residue on the soil surface. Crop residues on the soil surface are positioned such that allelochemicals released by rain are close to the site of weed seed germination (Putnam, 1994; Teasdale et al., 1991). Therefore, there is considerable interest in determining the effect of crop residues on weeds in conservation tillage systems.

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The ability of plants to affect the germination or growth of other plants has been known for centuries (Putnam, 1994). In agricultural crop production the main concern has usually been the effect of toxins from one crop on the yield of the next crop (Guenzi et al., 1967; McCalla and Daley, 1948; Nielsen et al., 1960; Yakle and Cruse, 1984). On the Canadian prairies detrimental effects of toxins from *Brassica* spp. on the next year's wheat, barley, or flax crops have been reported (Gubbels and Kenaschuk, 1989; Horricks, 1969; Vera et al., 1987). Recent research has aimed at the exploitation of these toxins by developing methods for using them to selectively control weeds in crops (Putnam, 1994). In field experiments it is difficult to test all cropping sequences in the presence of all major weed species to fully understand the effect of crops on weeds. In addition there are potential complex interactions in the field among soil, weather, and allelopathic agents in determining final weed populations. Hence, germination and initial growth of weed seeds in petri-dish tests in the presence of plant extracts have been frequently used to assess the potential toxicity of one plant on another (Hegde and Miller, 1990; Hsu et al., 1989; Martin et al., 1990). Mason-Sedun et al. (1986) found that the toxicity ranking of *Brassica* spp. on wheat was similar in petri-dish, greenhouse, and field bioassays.

The objective of the research reported in this paper was to assess the effect of residues from major crop species grown on the Canadian prairies on several prevalent weed

species. The information will be useful in planning cropping sequences that reduce reliance on herbicides for weed control.

Materials and Methods

Collection and Preparation of Plant Material

Samples of Crystal winter canola (*Brassica napus* L.), Gazelle rye (*Secale cereale* L.), Galt barley (*Hordeum vulgare* L.), Cascade oats (*Avena sativa* L.), Indian Head lentil (*Lens culinaris* Medic), and Katepwa wheat (*Triticum aestivum* L.) were collected from field plots in July 1993. Crop stages at collection were; wheat and oats at the beginning of anthesis, barley and rye at the end of anthesis, lentils at beginning of flowering, and winter canola (spring planted) nine or more leaves unfolded but no shoots formed. The stages were chosen to match treatments in an accompanying experiment that is still in progress, in which short-term cover crops are used to control weeds on summer fallow. All samples were air dried at room temperature and subsamples were ground to pass through a 3-mm sieve.

Preparation of Crop Extracts

Procedures for extraction of plant samples and the bioassay for toxins were adapted from Hegde and Miller (1990). Plant material was extracted with 200 ml of distilled water that had been autoclaved at 121°C for 10 min. Separate extracts were made of each crop species at concentrations of 1, 2, and 4% dry matter. Two extraction durations were used: 1) extraction for 1 hour in 250 ml flasks on a platform shaker and 2) extraction for four days on a platform shaker. The flasks were covered with rubber stoppers with small air vent tubes to maintain aerobic conditions and permit microbial modification of allelochemicals during extraction. Following extraction, coarse plant material was removed with a 2-mm sieve, extracts were passed through a Whatman #42 filter paper and centrifuged at 12,000 rpm for 20 min. The extracts were then filter sterilized by passage through a micropore filter (0.45 μm) into sterilized containers. Dilutions were made from the 1% dry matter extract to obtain the 0.1 and 0.5% dry matter extracts. The extracts were stored at 0.5°C to limit degradation of the allelochemicals.

Bioassay Techniques

To assess the effect of the extracts on germination and initial weed growth, the following procedure was used. Ten seeds per replicate of each weed species or crop were placed in petri-dishes on a Whatman #1 filter paper, and 4 ml of plant extract was added. An additional 1 or 2 ml of extract was added as required to maintain seedling development for a 7 day period. The petri-dishes were placed in plastic bags, stored in the dark at 22°C BC for 48 h, and exposed to light for 16 h/day (400 $\mu E/m^2/s$ at petri-dish height) for an additional 5 days. At the end of the test period percent germination, root length, and shoot length were measured. To obtain an estimate of the effect of the extracts on germination and initial growth of each weed species, a single replicate experiment was conducted with each weed species using 0.1, 0.5, 1, 2, and 4% extracts of each plant material. Then, a four-replicate experiment with a completely randomized design was conducted with three concentrations of each plant extract and a check treatment of distilled water. The concentrations of plant extracts were chosen so that the most dilute solution of at least one plant extract appeared to affect initial growth and the most concentrated solution did not stop germination. Four-replicate bioassays were conducted with the following weeds: downy brome (*Bromus tectorum* L.), flixweed (*Descurainia sophia* L. Webb), stinkweed (*Thlaspi arvense* L.), wild oat (*Avena fatua* L.), green foxtail (*Setaria viridis* L. Beauv.), redroot pigweed (*Amaranthus retroflexus* L.), kochia (*Kochia scoperia* L. Schrader), Russian thistle (*Salsola pestifer* A. Nels.), dandelion (*Taraxacum officinale* Weber), foxtail barley (*Hordeum jubatum* L.), and wheat. Each bioassay was set up as a factorial with three factors: 1) plant extract (Crystal canola, Gazelle rye, Galt barley, Cascade oats, Indian Head lentil, Katepwa wheat, and distilled water as check), 2) length of extraction (1 h and 4 days), and 3) concentration of extract.

Postexposure Germination of Weed Seeds

Bioassays were conducted using the previously described procedure and plant extract concentrations of 2% with flixweed, downy brome, redroot pigweed, and kochia. The plant extract concentration used with stinkweed and dandelion was 1%, and as in previous tests germination in distilled water was included as check. Seeds that did not germinate in the initial bioassay were removed from the petri-dishes and rinsed three times with 50 ml of autoclaved distilled water in 250 ml flasks. With each rinse the flasks were placed on a platform shaker for 10 min. The seeds were then placed in petri-dishes on Whatman #1 filter paper and 4 ml of water were added. The seven day germination test described previously was repeated. The number of seeds that germinated in the plant extracts, in distilled water, and total germination was determined and compared with the number that germinated when seeds were only exposed to distilled water.

Statistical Analyses

Germination, shoot length and root length data for each weed species and wheat were subjected to separate analysis of variance. Factors included in the initial analyses were plant extract, length of extraction, and concentration of extract. The data were reanalyzed by concentration to avoid complex interaction terms. Extract and total seed germination data in the test where seeds were removed from the extracts were also subjected to analysis of variance. Differences among means were examined using Tukey's procedure for the initial bioassays, and total germination in extracts plus water was compared with germination in water using Dunett's test. All statistical analyses were carried out using the GLM procedure of SAS (SAS Institute, 1989).

Results

Effect of Plant Extracts on Winter Annual Weeds

The seven day bioassay tests permitted assessment of the effect of the plant extracts on weed germination, initial root growth, and shoot growth as demonstrated for canola extract on downy brome and wheat (Figure 1).

In prelimimary tests either germination or initial growth of downy brome, flixweed, and stinkweed was reduced by lentil or canola extracts at 0.1% concentration. Concentrations required to affect growth varied by weed species and plant extract; therefore, different rate ranges were chosen for each weed species. In the factorial experiments the plant extract and the concentration of the extract significantly ($P \leq 0.05$) affected all growth indicators (germination, shoot growth, and root growth) for these three winter annual weeds (weeds that germinate in fall, survive the winter, and mature early the following summer). The overall effect of duration of extraction was not significant ($P \geq 0.05$) for the three winter annual weeds; however, there was a significant duration of extraction by extract interaction for downy brome germination and stem growth in plant extracts at 0.1 and 1% concentration. The significant time by extract interaction corresponds with an increase in germination and stem length of downy brome when extraction time increased from 1 hour to 4 days for oat and lentil extracts while both growth indicators decreased when extraction time increased from 1 hour to 4 days for barley extracts (Figure 2).

Downy brome germination was reduced by 0.1% lentil and oat extracts compared to germination in water (Table 1). One percent extracts of all six plant materials reduced downy brome germination compared to that in water. Initial root growth was affected by all plant extracts at 0.1%. Downy brome root growth was inhibited most by lentil and canola extracts. Stem length was only reduced in oat and lentil extracts at 0.1% concentration compared to water. At 1% concentration stem length was affected by all plant extracts and extracts from oat and lentil continued to have the greatest effect.

Of the six crop extracts only that of lentil significantly reduced flixweed germination at extract concentrations of 0.25 and 0.5% compared to water (Table 1). All six crop extracts reduced root length compared to water, and there was little difference in root length among the extracts.

Stinkweed germination was reduced by lentil, canola, barley, and oats at 0.5% concentration compared to water (Table 1). Root growth was reduced compared to water by lentil and canola at 0.1% concentration and was affected by all extracts at higher concentrations. Only lentil extract inhibited shoot growth at 0.1% concentration while all extracts effectively inhibited shoot growth at the higher concentrations.

Effect of Plant Extracts on Summer Annual Broadleaf Weeds

In the factorial experiments, plant extracts and concentration of the plant extracts significantly ($P \leq 0.05$) affected all growth indicators for redroot pigweed, Russian thistle, and kochia. The duration of extraction by extract interaction was not significant in most instances; however, it was significant ($P \geq 0.05$) for all growth indicators with redroot pigweed at the 2% extract concentration. The significant interaction corresponds with reductions in germination and stem length as the extraction duration increased from 1 hour to 4 days with wheat and lentil and no changes or an increase in growth indicators as duration of extraction increased with canola (Figure 3).

Canola extract at 0.1% concentration stimulated redroot pigweed shoot growth compared to water (Table 2). Germination of redroot pigweed was only inhibited by lentil extracts at 1 and 2%. Root growth was reduced by all

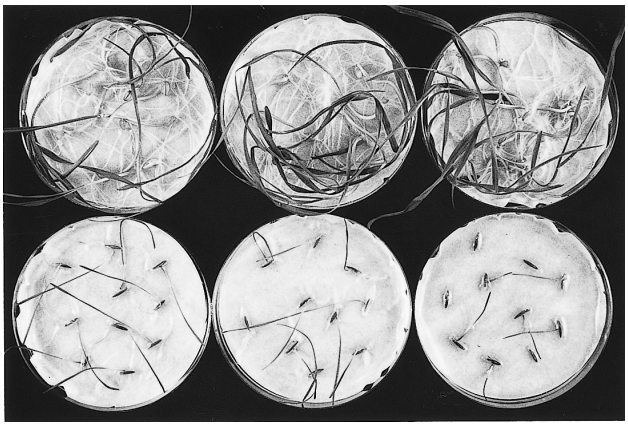

Figure 1. Effect of canola residue extracts on germination and initial growth of wheat (top) and downy brome (bottom). Concentrations, left to right, are 0 (water), 0.1, and 1% canola extract.

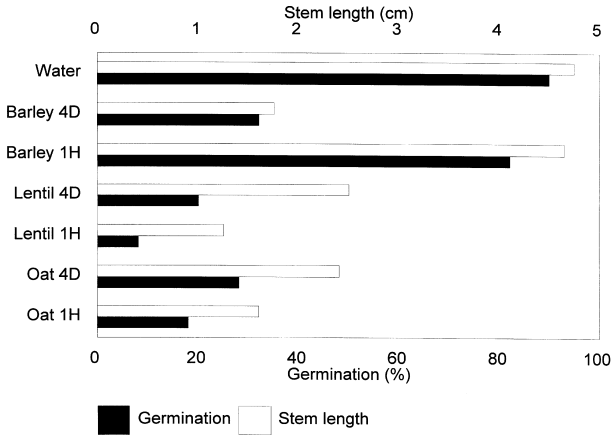

Figure 2. Effect of extraction duration on downy brome response to 1% concentration of selected crop extracts. SEM for stem length = 0.33 cm and SEM for germination = 8.7%; D = day and H = hour.

extracts at 1 and 2% compared to water but was only reduced by lentil extract at 0.1%. Shoot growth was only reduced compared to water by lentil extract at 2%.

Russian thistle shoot growth, similar to redroot pigweed, was stimulated by canola extracts at 0.1 to 2% (Table 2). None of the six crop extracts inhibited Russian thistle germination. Russian thistle root growth was reduced compared to water by all extracts at 1 and 2% except canola. Stem length was only reduced by oat extract at 2%.

Kochia germination was only inhibited by oat and lentil extracts at 2% (Table 2). Kochia root growth was reduced compared to water by all extracts at 1 and 2%. Lentil, oat, and canola extracts were the most effective in suppressing root growth. Lentil and canola extracts were the most effective in suppressing kochia shoot growth as only these two extracts suppressed growth at 1% concentration.

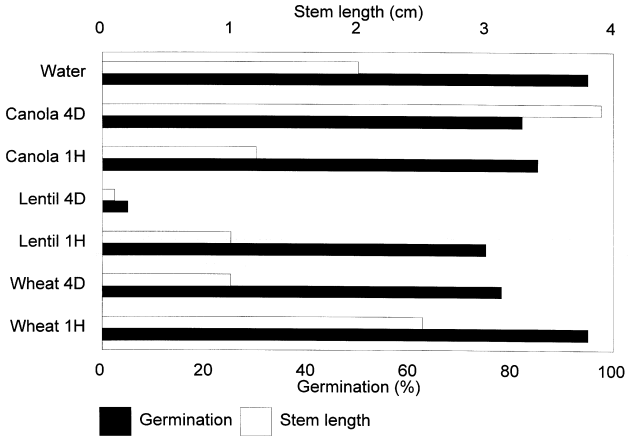

Figure 3. Effect of extraction duration on redroot pigweed response to 2% concentration of selected crop extracts. SEM for stem length = 0.66 cm and SEM for germination = 6.2%; D = day and H = hour.

Table 1. Effect of six crop extracts on germination and initial growth of three winter annual weeds: downy brome (A), flixweed (B), and stinkweed (C).

Extract	Germination (%)			Root length (cm)			Shoot length (cm)		
A. Downy brome									
	Extract Concentration (%)								
	0.1	1.0	2.0	0.1	1.0	2.0	0.1	1.0	2.0
Water	99a	98a	96a	7.2a	6.4a	6.2a	4.6ab	4.8a	4.4a
Canola	94ab	54cd	14c	1.4e	0.1b	0.0b	4.5ab	1.6de	0.3c
Barley	76bc	64b-d	18c	3.0c	0.6b	0.0b	3.7bc	2.7bc	0.4c
Rye	96ab	86ab	69b	4.4b	0.8b	0.8b	4.8ab	3.3b	2.4b
Wheat	99a	83a-c	25c	4.4b	0.6b	0.1b	4.9a	2.3cd	0.3c
Oat	68c	40d	8c	2.1c	0.4b	0.0b	3.1c	1.2ef	0.1c
Lentil	68c	38d	15c	0.8e	0.2b	0.0b	2.7c	0.7f	0.2c
B. Flixweed									
	Extract Concentration (%)								
	0.1	0.25	0.5	0.1	0.25	0.5	0.1	0.25	0.5
Water	65	62ab	55a	0.6a	0.6a	0.6a	0.2	0.3ab	0.2ab
Canola	48	45a-c	29ab	0.2c	0.2bc	0.1b	0.3	0.2ab	0.1bc
Barley	45	51ab	29ab	0.3bc	0.2bc	0.1b	0.4	0.3ab	0.2ab
Rye	48	33bc	26ab	0.3bc	0.2bc	0.1b	0.2	0.1bc	0.1bc
Wheat	68	68a	41a	0.5ab	0.3b	0.2b	0.4	0.4a	0.3a
Oat	54	46a-c	57a	0.3bc	0.1bc	0.2b	0.4	0.3ab	0.3a
Lentil	46ns	14c	1b	0.2c	0.0c	0.0b	0.3ns	0.0c	0.0c
C. Stinkweed									
	Extract Concentration (%)								
	0.1	0.5	1.0	0.1	0.5	1.0	0.1	0.5	1.0
Water	92	85a	88a	2.8a	2.7a	3.1a	1.3a	1.3a	1.4a
Canola	72	22c	9de	1.2b	0.0c	0.0c	1.0ab	0.1cd	0.0c
Barley	85	52b	18c-e	1.7ab	0.4bc	0.1c	1.2a	0.4bc	0.1c
Rye	92	64ab	36bc	2.1ab	1.0b	0.3bc	1.2a	0.6b	0.2bc
Wheat	80	72ab	56b	2.2ab	1.2b	0.7b	1.0ab	0.8b	0.5b
Oat	91	52b	33b-d	1.8ab	0.6bc	0.2bc	1.4a	0.6b	0.2bc
Lentil	70ns	14c	2e	1.1b	0.0c	0.0c	0.7b	0.1d	0.0c

a-f: Means within a column for each weed that are followed by the same letter are not significantly different, according to Tukey's test ($P \leq 0.05$); means within a column for each weed where the last number is followed by ns are not significantly different ($P > 0.05$).

Effect of Crop Extracts on Annual Grass Weeds and Wheat

The overall effect of plant extract and concentration was significant ($P \leq 0.05$) for almost all growth indicators with green foxtail, wild oat, and wheat. As with the winter annual and summer annual broadleaf weeds, the overall effect of time was usually not significant ($P \geq 0.05$). There were instances where length of extraction by extract interaction was significant ($P \leq 0.05$). All growth indicators for wild oat exhibited a greater suppression due to crop extracts, compared to water, in 1 hour than 4 day extracts for 1% extract concentration. A similar trend of decreasing suppressive effect of extracts with time of extraction occurred for germination of wheat in 1% extracts and for green foxtail root length in 0.1% extracts.

Green foxtail germination was not suppressed by any of the extracts (Table 3). Root growth was suppressed by lentil, canola, and oat extracts at 0.1%. At 1% and 2% all extracts suppressed root growth. Shoot growth was not affected by any plant extracts at 0.1% and was only suppressed by lentil extract at 1%. Lentil, canola, and barley extracts at 2% suppressed green foxtail shoot growth.

Wild oat germination was suppressed by oat and canola extracts at 4% (Table 3). All plant extracts at all concentrations suppressed wild oat root growth. Shoot growth was only suppressed by lentil and canola extracts at 1%. At 4% all plant extracts suppressed shoot growth.

Wheat germination was reduced by lentil, oat, and canola extracts at 4% (Table 3). Wheat root growth was suppressed by all plant extracts except wheat at 1%. None of the extracts inhibited shoot growth at 1%. At 2% extracts of lentil, oat, and canola inhibited wheat shoot growth, and at 4% all plant extracts inhibited shoot growth.

Effect of Plant Extracts on Dandelion and Foxtail Barley

Dandelion germination and shoot growth were reduced by lentil extract at 0.5 or 1% and by canola at 1% compared to water (Table 4). Dandelion root growth was inhibited by lentil extract at 0.5% and by all extracts at 1%.

Table 2. Effect of six crop extracts on germination and initial growth of three annual broadleaved weeds: redroot pigweed (A), Russian thistle (B), and kochia (C).

Extract	Germination (%)			Root length (cm)			Shoot length (cm)		
A. Redroot Pigweed									
	Extract Concentration (%)								
	0.1	1.0	2.0	0.1	1.0	2.0	0.1	1.0	2.0
Water	96	95a	95ab	4.1a	3.8a	3.8a	1.8b	1.8	2.0ab
Canola	95	90a	84a	3.0ab	1.2b	0.8b	4.1a	3.3	2.6a
Barley	98	89a	83ab	3.0ab	1.2b	0.5bc	2.8ab	2.7	1.7ab
Rye	89	94a	75ab	2.5ab	1.0b	0.5bc	2.5ab	2.8	1.9ab
Wheat	84	93a	86ab	2.5ab	1.2b	0.7b	2.1ab	2.4	1.8ab
Oat	88	96a	76ab	2.5ab	0.9b	0.5bc	2.6ab	2.9	2.1ab
Lentil	96ns	70b	40b	2.1b	0.4b	0.2c	2.6ab	2.0ns	0.6b
B. Russian thistle									
	Extract Concentration (%)								
	0.1	1.0	2.0	0.1	1.0	2.0	0.1	1.0	2.0
Water	95	94	95	4.2b	3.7a	3.8a	3.5b	3.6b	3.3b
Canola	94	84	86	9.4a	4.9a	4.2a	10.2a	9.4a	9.3a
Barley	96	88	86	3.1b	1.7b	0.7bc	3.7b	2.9b	1.9bc
Rye	93	94	89	3.6b	2.1b	1.4bc	3.5b	3.2b	2.8bc
Wheat	99	94	93	4.0b	1.8b	2.0b	3.8b	3.3b	3.2bc
Oat	96	85	78	2.9b	1.3b	0.5c	3.8b	2.7b	1.7c
Lentil	94ns	93ns	89ns	3.0b	1.6b	0.9bc	3.6b	2.8b	2.2bc
C. Kochia									
	Extract Concentration (%)								
	0.1	1.0	2.0	0.1	1.0	2.0	0.1	1.0	2.0
Water	86	86	92a	1.8	2.3a	2.2a	1.1	1.1a	1.3a
Canola	89	83	60ab	1.4	0.2c	0.1c	1.1	0.6c	0.2c
Barley	96	92	75ab	1.6	0.6bc	0.2bc	1.2	1.1a	0.5bc
Rye	95	82	84ab	2.2	0.7bc	0.5bc	1.4	1.0ab	0.9ab
Wheat	91	94	88ab	2.1	1.1b	0.6b	1.2	1.2a	0.9ab
Oat	90	86	55b	1.4	0.3c	0.1c	1.2	0.8a-c	0.3c
Lentil	95ns	76ns	52b	1.4ns	0.2c	0.1c	1.2ns	0.5c	0.2c

a-c: Means within a column for each weed that are followed by the same letter are not significantly different according to Tukey's test ($P \leq 0.05$); means within a column for each weed where the last number is followed by ns are not significantly different ($P > 0.05$).

Table 3. Effect of six crop extracts on germination and initial growth of three annual grasses: green foxtail (A), wild oat (B), and wheat (C).

Extract	Germination (%)			Root length (cm)			Shoot length (cm)		
A. Green foxtail									
	Extract Concentration (%)								
	0.1	1.0	2.0	0.1	1.0	2.0	0.1	1.0	2.0
Water	94	100	98	4.1a	4.3a	4.3a	2.8	3.0a-c	3.1a
Canola	98	96	75	2.2c	0.6bc	0.3b	3.3	3.3a	1.9b
Barley	99	92	85	4.4a	1.4b	0.9b	3.3	2.4b-d	1.9b
Rye	99	99	98	3.4ab	1.0bc	1.0b	3.4	3.4a	3.2a
Wheat	98	96	96	3.4ab	0.7bc	0.9b	3.4	3.3a	2.4ab
Oat	96	95	79	3.0bc	1.1bc	1.0b	2.9	2.2cd	2.2ab
Lentil	95ns	90ns	82ns	0.8d	0.3c	0.4b	2.4ns	1.8d	1.8b
B. Wild oat									
	Extract Concentration (%)								
	1.0	2.0	4.0	1.0	2.0	4.0	1.0	2.0	4.0
Water	99a	93	99a	7.1a	6.0a	6.9a	7.2a	6.5a	7.0a
Canola	96ab	80	52bc	0.6c	0.3b	0.1b	4.0b	1.8dc	0.6d
Barley	94ab	91	72ab	3.0b	0.8b	0.2b	6.7a	5.9ab	1.6cd
Rye	94ab	89	90a	1.2bc	0.7b	0.7b	5.8ab	4.8ab	3.9b
Wheat	95ab	95	86a	1.4bc	0.8b	0.7b	5.7ab	3.8bc	3.1bc
Oat	91ab	82	36c	2.6b	0.9b	0.2b	5.7ab	2.8cd	0.6d
Lentil	86b	85ns	74ab	0.4c	0.3b	0.2b	1.7c	1.0d	0.6d
C. Wheat									
	Extract Concentration (%)								
	1.0	2.0	4.0	1.0	2.0	4.0	1.0	2.0	4.0
Water	99a	98	96a	8.9a	9.2a	8.6a	7.5	7.8a	7.8a
Canola	85b	85	56c	3.1d	2.5cd	0.9d	6.2	4.7cd	1.8d
Barley	94a	91	80ab	3.9cd	2.9cd	1.4cd	6.7	6.4a-c	4.1bc
Rye	91a	96	86ab	5.8bc	4.4bc	2.9bc	7.3	7.1ab	5.6b
Wheat	92a	92	89ab	7.2ab	5.1b	3.5b	7.7	7.2a	5.4b
Oat	95a	85	59c	5.9bc	3.2cd	1.9b-d	7.7	5.2b-d	3.5c
Lentil	93a	86ns	75bc	4.2cd	2.0d	1.9b-d	6.2ns	3.6d	3.6c

a-d: Means within a column for each weed that are followed by the same letter are not significantly different according to Tukey's test ($P \leq 0.05$); means within a column for each weed where the last number is followed by ns are not significantly different ($P>0.05$).

The effect of duration of extraction was significant ($P \leq 0.05$) for all growth indicators in 0.5% extracts and for stem length in 1% extracts. The duration by extract interaction was not significant for any growth indicator at any concentration. When length of extraction was significant, there was a reduction in either percent germination, shoot length, or root length as extraction duration increased from 1 hour to 4 days.

Foxtail barley response to the plant extracts at 1% concentration was different from most of the other weed responses. At this concentration germination and shoot growth were stimulated by canola, barley and wheat, or rye extracts (Table 4). In contrast foxtail barley root growth was suppressed by all plant extracts at 1% concentration or greater. There were significant ($P \leq 0.05$) effects of length of extraction by extract interactions for root response to 2 and 4% extracts. The inhibition in root growth decreased as the length of extraction increased for barley and lentil but was similar for the two lengths of extraction for the other plant extracts.

Postexposure Germination of Weed Seeds

In all crop extracts germination was reduced compared to water (Table 5). Additional weed seeds germinated when the seeds were removed from the crop extracts, rinsed, and allowed to germinate in distilled water, except for stinkweed seeds that were subjected to lentil extract. In this case no additional seeds germinated in water. Total stinkweed germination in crop extract plus water was less when the seeds were subjected to barley, lentil, and oat extracts than germination after exposure to only water (Table 5). In addition, exposure of downy brome, redroot pigweed, and kochia to crop extracts reduced total germination except for flixweed and pigweed exposure to rye extract. In contrast total dandelion germination was similar in water only and in crop extracts plus water. The inability of weed seeds, except dandelion, to reach germination percentages observed in water after exposure to selected crop extracts indicates seed viability was reduced or dormancy increased by exposure to the crop extracts.

Table 4. Effect of six crop extracts on germination and initial growth of two perennial weeds: dandelion (A) and foxtail barley (B).

Extract	Germination (%)			Root length (cm)			Shoot length (cm)		
A. Dandelion									
	Extract Concentration (%)								
	0.1	1.5	1.0	0.1	0.5	1.0	0.1	0.5	1.0
Water	80	76a	77a	1.4	1.0a	1.3a	0.7	0.6a	0.6a
Canola	83	59ab	40bc	1.2	0.6ab	0.1c	0.8	0.5ab	0.3bc
Barley	84	78a	61ab	1.3	0.9a	0.5bc	0.7	0.7a	0.5ab
Rye	80	63ab	55a-c	1.3	0.8ab	0.5bc	0.7	0.5ab	0.4a-c
Wheat	75	54ab	69ab	1.2	0.7ab	0.7b	0.6	0.5ab	0.6a
Oat	86	68ab	49a-c	1.4	0.9a	0.3bc	0.8	0.6a	0.4a-c
Lentil	78ns	41b	25c	1.1ns	0.4b	0.1c	0.6ns	0.3b	0.2c
B. Foxtail barley									
	Extract Concentration (%)								
	1.0	2.0	4.0	1.0	2.0	4.0	1.0	2.0	4.0
Water	78c	86	85ab	4.1a	4.3a	4.2a	3.7b	4.0ab	3.8bc
Canola	93ab	80	75b	1.2d	0.3e	0.1d	4.7a	3.8b	2.8c
Barley	95a	91	82ab	2.4bc	1.6cd	1.0c	5.0a	4.9a	4.1b
Rye	89a-c	86	92a	2.5bc	2.4cb	1.3c	4.7a	4.5ab	5.2a
Wheat	81bc	81	76ab	3.0b	3.0b	2.5b	4.5ab	4.1ab	4.0b
Oat	84a-c	82	86ab	1.9cd	1.9cd	1.0c	4.2ab	4.4ab	4.4ab
Lentil	86a-c	82ns	86ab	2.1bc	1.5d	0.8cd	4.3ab	3.9b	4.0b

a-d: Means within a column for each weed that are followed by the same letter are not significantly different according to Tukey's test ($P \leq 0.05$); means within a column for each weed where the last number is followed by ns are not significantly different ($P > 0.05$).

Table 5. Postexposure germination of weed seeds.[a]

	Initial extract											
	Concentration 1%						Concentration 2%					
Initial	Stinkweed		Dandelion		Flix weed		Downy brome		Redroot pigweed		Kochia	
Extract	Initial	Total	Initial	Total	Initial	Total	Initial	Total	Initial	Total	Initial	Total
	Percent Germination											
Barley	11*	22*	28*	55	5*	35*						
Canola	0*	0*	21*	43	2*	33*					2*	5*
Lentil	15*	15*	31*	62	0*	33*	12*	25*	38*	75*	11*	23*
Rye	21*	43	28*	55	2*	65			41*	82		
Oat	11*	22*	28*	55			2*	5*			10*	20*
Water	55	55	58	58	64	64	93	93	96	96	66	66

[a]Seeds not germinated after exposure to crop extract for 7 days, rinsed and allowed to germinate in water for an additional 7 days. Initial germination in the extracts and total germination in extracts plus water are reported.
*Means within a column are significantly different from the check (water) ($P \leq 0.05$) by Dunnett's test.

Discussion

In this study some crop extracts were more toxic to some weeds than canola extract was to wheat. Previous reports indicate reduced wheat germination and growth occur on producer fields and in experiments in western Canada the year following a *Brassica* crop (Horricks, 1969; Vera et al., 1987). Suppression of wheat growth and yields occurred primarily in the area behind the combine where the canola residue was discharged (Horricks, 1969). The toxic effect of *Brassica* spp. may be caused by hydrolysis products of glucosinolates that occur in substantial amounts in the vegetative parts of *Brassica* spp. (Vera et al., 1987). Differences between *Brassica* spp. in their ability to suppress cereal growth have been observed in some tests (Mason-Sedun et al., 1986) while all species had a similar effect in other tests (Vera et al., 1987). Effective combine straw spreaders and new low glucosinolate canola varieties have resulted in fewer producer complaints regarding reduced cereal yield after canola.

In our study wheat germination was slightly reduced, and root growth was reduced by 50% in 1% canola extracts compared to water. In comparison, lentil, oat, canola, and barley extracts at 1% or less caused substantial reduc-

tions in downy brome, flixweed, and stinkweed germination and growth. Downy brome, flixweed, and stinkweed are winter annual weeds that germinate after harvest in autumn, survive through the winter, and resume growth early in spring. Therefore, these are weeds that compete with winter wheat and are major weeds in no-tillage systems (Blackshaw, 1990; Blackshaw and Lindwall, 1995). Because the weeds germinate soon after harvest, they will be exposed to the maximum concentration of allelopathic agents from crop residues. Most toxic compounds from plants do not persist for long periods in soil (Devine et al., 1993). In our study, for example, the toxicity of the extracts from oat and lentil to downy brome decreased between a one hour extraction and a four day extraction. Therefore, the most likely beneficial use of toxins from plant residues is for winter annual weed control in winter wheat or winter annual control in conservation tillage systems. Our results indicate winter wheat will have considerably more tolerance than the winter annual weeds to the toxins from lentil, canola, oat, and barley. Lentil extract was one of the most effective in suppressing germination and initial growth of winter annuals. Field observations indicated that winter wheat growth and germination was only suppressed in no-tillage fields in patches where lentil residues were heavily concentrated (Cochran et al., 1977).

Plant extract concentrations that were required to suppress the other annual broadleaf weeds and grasses, in our study, were closer to those required for wheat growth suppression than winter annual weed suppression. Therefore, expected results in the field should be similar to the occasional suppression in wheat growth that is observed in farm fields with the main effect being in areas where plant residues are concentrated.

Dandelion germination and root growth were substantially reduced by 1% extracts of lentil and canola residues. However, this weed usually germinates in spring and summer and the toxins from the plant residues will likely dissipate before dandelion germination occurs. In addition, dandelion seeds that were exposed to residue extracts and then placed in water germinated normally.

Future plans are to conduct field experiments to assess winter annual weed control in winter wheat and conservation tillage systems after lentil, oat, canola, or barley crops.

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