Iranian Journal of Weed Science (2005), Volume 1, No., 1, 19-40

Early Root and Shoot Competition between Spring Cereal Cultivars and Wild Mustard (*Brassica kaber*)

M A. Baghesani-Meybodi[1], C. Lemieux[2] and G. Leroux[3]

[1] Research Scientist, Weed Research Department, Plant Pests and Diseases Research Institute, P.O. Box 1454, Tehran 19395, Iran; [2] Research Scientist, Agriculture and Agri-Food Canada, 2560 Hochelaga Blvd.,Sainte-Foy, QC, Canada G1V 2J3; [3] Professor, Department of Plant Science, Laval University, Sainte-Foy, QC, Canada G1K 7P4

(Received 9 November 2004; returned 16 January 2005; accepted 1 February 2005)

The use of more competitive species and cultivars in small grain cereal production may help to develop production systems that require less herbicide. This study was designed to identify root and shoot characteristics of cereal seedlings that would allow distinguishing the more competitive (MC) cultivars from the less competitive (LC) ones. Two growth cabinet trials were conducted using four crops: two-row barley, six-row barley, oat, and wheat. A total of twelve cultivars (six classified *a priori* as MC and six classified *a priori* as LC) were grown with and without wild mustard. The inhibitory effects of the MC cultivars on wild mustard growth were not systematically larger than those of the LC cultivars at 3 weeks after emergence. Oat was found to be more competitive than two-row and six-row barley. Wild mustard adversely affected the above-ground growth of two-row barley and oat but had no effect on below-ground growth; shoot competition may precede root competition. For two-row barley, oat, and wheat competing with wild mustard,

Correspondence to: M.A. Baghestani Meybodi , E-mail: Baghestani@ppdri.ac.ir

growth of MC cultivars was superior to that of LC cultivars. Only MC oat and wheat cultivars produced more above- and below-ground growth than LC cultivars while exerting a greater competitive effect on wild mustard growth. These results suggest that it may be possible to select oat and wheat cultivars for greater competitive ability against wild mustard based on root and shoot characteristics.
Key words: Small grain cereals, crop competitive ability, cultivar competitive ability.

در مدیریت علف‌های‌هرز، استفاده از ارقامی با توانایی رقابتی بالا از ابزارهایی است که برای کاهش مصرف علف‌کش‌های شیمیایی استفاده می‌شود. این بررسی بمنظور شناسایی ویژگی‌های اندام‌های هوایی و زیرزمینی دانه‌رست غلات که سبب تشخیص ارقام رقیب از غیر رقیب آنها می شود، در اتاق رشد انجام شد. برای این منظور دوازده رقم (شش رقم رقیب و شش رقم غیر رقیب) غلات شامل گندم، یولاف زراعی، جو دو ردیفه و شش ردیفه در حضور و غیاب خردل وحشی کشت گردید. نتایج نشان داد که اثرات بازدارندگی ارقام رقیب تا ۳ هفته پس از رویش خردل وحشی بر رشد علف‌هرز بروز نکرد. در بین غلات مورد بررسی، تنها یولاف زراعی از قدرت رقابتی بیشتری نسبت به جو دو ردیفه برخوردار بود و سایر غلات با یکدیگر تفاوت معنی‌داری نشان ندادند. حضور خردل وحشی در مجاورت جو دو ردیفه و یولاف زراعی اثر منفی بر رشد اندام‌های هوایی این دو گیاه زراعی گذاشت، ولی تاثیری بر رشد اندام‌های زیرزمینی آنها نداشت. نتایج نشان داد که در مجموع، رقابت هوایی بین خردل وحشی با غلات مورد بررسی زودتر از رقابت زیرزمینی شروع می‌شود. در حضور خردل وحشی تنها ارقام رقیب یولاف زراعی و گندم از رشد اندام‌های هوایی بیشتری نسبت به ارقام غیر رقیب برخوردار بودند. نتایج نشان داد که امکان انتخاب ارقام رقیب از غیر رقیب گندم و یولاف زراعی با استفاده از ویژگی‌های هوایی و زیرزمینی دانه‌رست آنها امکان‌پذیر می‌باشد.

INTRODUCTION

Concerns over the economic and environmental impact of modern agriculture have raised interest in production systems that require fewer chemical applications (Hallberg, 1987; Liebman & Robichaux, 1990). One way to reduce herbicide applications is to use crop competition to suppress weed growth and reproduction (Callaway, 1992; Challaiah *et al*., 1986; James *et al*., 1988). Crop species and cultivars that rapidly develop tall leafy shoots and long branched roots are reportedly more competitive than other species and cultivars (Bozsa & Oliver, 1990; Evetts & Burnside 1973; Monks *et al*., 1988; Richards & Davies 1991; Rooney, 1991). Above-ground competition has been perceived as determining the outcome of crop and weed interactions (Zimdahl, 1991; Dunan & Grundy & Froud-Williams, 1993; Verschwele & Nieman, 1994; Christensen, 1995), but below-ground competition may also be key (Pavlychenko, 1937; Hackett, 1969; Wilson, 1988; Wang & Below, 1992; Arnone III & Kestenholz, 1997).

Species and cultivars of small grain cereals differ in shoot and root morphology; these differences can affect grain yield and crop competitiveness against weeds. Dunan & Zimdahl (1991) report that barley is a stronger competitor than wild oat because it has a greater leaf area, root and shoot biomass, absolute growth rate, and shoot to root ratio. Mian *et al*.(1993) identified differences in the root and shoot characteristics of winter wheat genotypes. Wheat genotypes with larger root systems produce more grain than those with smaller root systems (Mian *et al*., 1994). Variations in competitive ability of wheat (Wicks *et al*., 1986) and bean (*Phaseolus vulgaris* L.) (Wortmann, 1993) genotypes against weeds have also been reported.

Wild mustard is an annual weed that is prevalent in field crops throughout Europe and North America (Holm *et al*., 1997). In a series of surveys conducted in cereal fields across Canada from 1976 to 1997, the percentage of small grain cereal fields in which wild mustard was present was 48% in Québec and 57% in Manitoba (Warwick *et al*., 2000).

Competition with wild mustard can affect the growth of cereal crops (Dahl *et al*., 1982), and the reverse is also true (Liebman & Robichaux, 1990). As small grain cereals can help to suppress weed growth, breeders may be interested in implementing a program to select and develop more competitive species and cultivars (Callaway, 1992). In order to identify appropriate criteria for selecting competitive lines, we have looked at crop/weed interactions between spring cereals and wild mustard seedlings. The first objective of this study was to identify root and shoot characteristics of cereal seedlings to distinguish the more competitive (MC) cereal cultivars from the less competitive (LC) ones. The second objective was to determine the effect of wild mustard on the root and shoot development of cereal crops.

MATERIALS AND METHODS

The first trial of this experiment was established at the Agriculture and Agri-Food Canada Research Centre at Sainte-Foy, QC, Canada, in December 1995 (trial № 1). The experiment was repeated in December 1996 (trial № 2). Four spring cereals were used: two-row barley (two cultivars), six-row barley (two cultivars), oat (four cultivars), and wheat (four cultivars). These twelve cultivars were selected on the basis of weed response to crop competition (Table 1). Weed response was evaluated by measuring weed density and dry weight at Zadok-39 crop growth stage (flag-leaf expansion) in preliminary field-scale screening tests involving 40 spring cereal cultivars (Preradov-Odobasic 1997); selected cultivars were classified *a priori* as MC or LC (Table 1). Each cultivar was grown with and without wild mustard. A total of 25 treatments (including a treatment of wild mustard alone) were arranged in a randomized complete block design with four replicates.

Table1. Spring cereal cultivars selected based on the results of a field-scale screening test involving 40 cultivars (Preradov-Odobasic 1997); following this preliminary work, selected cultivars were *a priori* classsified as more-competitive or less-competitive

Crop	More-competitive cultivars	Less competitive cultivars
Two-way barley	Winthrop	Iona
Six-way barley	Chapais	Cadette
Oat	Ac-Rigodon	Laurent
Oat	Donegal	Ultima
Wheat	AC-Pollet	Celtic
Wheat	SS-Blomidon	Roblin

Plants were established in a walk-in growth chamber with a 16h/8h light and dark period, light being provided by fluorescent tubes at an intensity of 610 μE m^{-2} s^{-1} at plant level. Air temperature was maintained at 21 °C/17 °C, day /night, with relative humidity ranging from 45 to 50%. Crop and wild mustard seeds were pre-germinated for 2 days in Petri dishes on top of a damp №1 Whatman filter. Germinating seeds were transferred into wooden boxes (100 cm long, 6 cm wide and 80 cm deep each containing 16 6- by 5- cm compartments. To prevent roots from sticking to the walls, compartments were lined with plastic bags (90 cm long, 9.5 cm diameter) that were perforated at the bottom. The compartments were filled with an inert medium (Turface™ [1]). Two germinating seeds of crop species and/or three germinating seeds of wild mustard were transplanted to a 2-cm depth in each compartment. After 3 days, emerged seedlings were thinned to one plant of the crop or wild mustard, or one each of cereal and wild mustard (in mixed treatments) per compartment. The plants were watered every other day, or as needed, and 4 L of single strength Hoagland's solution was supplied to each box every 4 days.

The net photosynthesis rate of the cereals was measured under ambient conditions 2 weeks after transplanting using a portable infrared gas analyzer system (LI-6200™). At the time of measurement, air temperature in the chamber was between 20 and 25 °C, relative humidity was between 30 and 35% and the base level of CO_2 concentration was between 300 and 400 ppm. The photosynthetic photon flux density (Q-Beam 2001-A™ [2]) was maintained at 2200 μE m^{-2} s^{-1}. Net photosynthesis was measured on the last fully-developed leaf as μmol CO_2 m^{-2} leaf area s^{-1}. Three readings were made per sample.

Root and shoot development of the seedlings were measured 3 weeks after transplanting. Crop height, from ground level to apex of longest leaf, number of wild mustard leaves, crop and wild mustard leaf area (LI-3100™[3]), and total above-ground dry weight (oven-dried at 65 °C for 72 h) of crop and wild mustard

[1] Applied Industrial Materials Corp., 750 Lake Cook Road, Suite 440, Buffalo Grove, IL60089, USA
[2] Quantum Devices, Inc., 112 Orbison Street, Barneveld, WI 53507, USA
[3] LI-COR, Inc., 4421 Superior Street, Lincoln, NE 68504, USA.

were measured. After sampling the above ground plant material, boxes were disassembled and the plastic bags from individual compartments were opened with a teasing needle and the roots extracted by washing away the growth medium with water. In the case of mixed treatments, root samples were floated in water and separated into cereal and wild mustard roots. These samples were stored in plastic bags at 4 °C until measured. At the time of measurement, roots were soaked for 5 minutes in an organic stain solution (3 g of Congo red[4] dissolved in 100 mL ethyl alcohol, and diluted in 3.3 L of distilled water), washed with clean water, and displayed on a 20-cm by 30-cm transparent dish containing 4 mm of water. Rooting depth, total root length, length of roots <1-mm diameter, length of roots ≥1-mm diameter, root surface area, root average diameter, and root dry weight (oven-dried at 65 °C for 72 h) were all measured. Root length, area and average diameter were measured using image analysis software (WinRHIZO™ V2.0[5]) coupled to a scanner at a resolution of 200 dots per inch.

Statistical analysis was in three steps. The first step was to obtain Pearson correlation coefficients among wild mustard traits and among crop traits. For any pair of traits presenting high correlation, one trait was dropped, as high correlation between two traits means they both convey similar information. Second, a principal component analysis (PCA) was run to identify dominant trends, to select the most appropriate traits to conduct ANOVA, and to select the most appropriate treatments for contrasts (Tacq, 1997). Third, treatment effects were assessed by ANOVA. The assumption of homogeneity of variance was tested using the Bartlett's test (Steel & Torrie 1980) and data were transformed to $\log_{10}$ scale, whenever necessary; in the latter cases, reported means were back-transformed. Single degree of freedom comparisons were used to test competitiveness of crops and cultivars. All statistical analysis were performed using SAS™ (SAS Institute Inc. 1989).

---

[4] Mallinckrodt Baker, Inc., 222 Red School Lane, Phillipsburg, NJ 08865, USA
[5] Régent Instruments, Inc., 165 Fatima Ave. Québec, QC, G1P 2C7, Canada.

RESULTS AND DISCUSSION

The Pearson correlation coefficients between total root length and length of roots smaller than 1-mm diameter was 0.97 ($P<0.0001$) for wild mustard and 0.93 ($P < 0.0001$) for cereals. We chose to remove total root length from the data set to ensure that the traits used to conduct the PCA were, as much as possible, independent from each other. The remaining data set, therefore, included data (observations) from two trials, four replicates, and 25 treatments, for which nine wild mustard traits (leaf number, leaf area, shoot dry weight, root dry weight, rooting depth, root surface area, length of small diameter (< 1 mm) roots, length of large diameter (≥ 1 mm) roots, and average root diameter) and 11 crop traits (plant height, leaf area, shoot dry weight, rooting depth, root dry weight, average root diameter, root surface area, length of small diameter (< 1 mm) roots, length of large diameter (≥ 1 mm) roots, net photosynthesis, and shoot to root ratio) were measured.

A PCA is a multivariate statistical technique that explores a complex set of response traits for the purpose of simplifying it to a set of new transformed traits; the principal components (PC) (Tacq, 1997). Each component is a linear combination of all the traits; for each subject (observations) the scores of a component are computed as the observed data value of each response trait, weighed by the loadings for that component (weight assigned to each response trait). The components, by definition, are orthogonal and the selection of a limited number of them accounts for a large proportion of the variability observed in the set of response traits. Usually two or three components describe the principal features of the system.

Using the PC, it becomes possible to position response traits and subjects (observations) within a two- or three-dimensional space. Such a graph allows traits to be selected according to their relative contribution to the PC. The scores of individual subjects can also be plotted and identified within a given category (in this case trial, crop, or cultivar). Differences in the dataset can be determined with respect to the categories represented on the graph.

For our data set, the PCA identified two PC which explained 48% of the total variation. The graphical representation of individual observations on a biplot for first and second PC, with scores identified by trials, indicated that data from both trials did not differ significantly (Figure 1-A). Therefore, further analyses were performed on combined data from the two trials.

The graphical representation of individual scores, identified by crop (Figure 1-B) and cultivar (Figure 1-C and 1-D), facilitated the identification of contrasts for the ANOVA. Figure 1-B shows that oat is slightly apart from the other three crops. Although observations from all four crops are spread more or less evenly along the first PC, their spread along the second PC axis differentiates oat from two-row barley, six-row barley, and wheat. This indicates that oat might be distinct from the other three crops. It also suggests that there is no need to establish contrasts to compare two-row barley, six-row barley, and wheat with each other. Figure 1-C shows the distribution of oat cultivars along the axes for first and second PC. Figure 1-D shows the distribution of wheat cultivars along the same axes. In these cases the capacity of one component to discriminate among cultivars is not as precise as that for crops. However, when positioning along both PC is considered, it is possible to identify relatively distinct groupings for the oat cultivars 'Rigodon' and 'Donegal' (Figure 1-C) and for the wheat cultivars 'SS-Blomidon' and 'AC-Pollet' (Figure 1-D). Both of these groupings correspond to the *a priori* competitiveness classification (Table 1). As a result, we established contrasts between oat and wheat cultivars according to the *a priori* competitiveness classification.

The position of crop and wild mustard traits along the first and second PC allows identification of crop traits that are in opposition with wild mustard (Figure 2). We chose to conduct ANOVA only on those traits. For crops they were: height, leaf area, shoots dry weight, root dry weight, root surface area, length of small diameter (< 1 mm) roots, and 200 length of large diameter (≥ 1 mm) roots. For wild mustard they were: leaf number, leaf area, shoots dry weight, root surface area, length of small diameter (< 1 mm) roots, and length of large diameter (≥ 1 mm) roots.

Competitive Effects

A competitive effect is the ability to suppress other individuals (Callaway 1992). In presence of a crop wild mustard produced significantly fewer leaves, less leaf area, biomass, root surface area, and shorter roots (Table 2). Oat and wheat did not have differential effect on wild mustard for any of the traits studied. However, the Inhibitory effect of oat on wild mustard growth was larger than that of two-row barley for length of small diameter roots, and larger than that of six-row barley for leaf area, length of small diameter roots, and root surface area. Within six-row barley, 'Chapais' was more detrimental than 'Cadette' for length of small diameter wild mustard roots and root surface area. Among oat cultivars, 'Ultima' was more detrimental to wild mustard leaf number than 'Laurent'; taken together, the two cultivars classified *a priori* as MC were more detrimental than the LC ones for length of small diameter wild mustard roots and root surface area. Among wheat cultivars, 'Celtic' was more detrimental to wild mustard leaf area than 'Roblin'; taken together, the two cultivars classified *a priori* as MC were more detrimental than the LC ones with respect to wild mustard leaf number, length of small and large diameter roots, and root surface area.

Although the effect of small grain cereals on wild mustard growth was significant and consistent for all above- and below-ground traits, the differential effect of crops and cultivars was not as consistent as expected. The inhibitory effects of the cultivars classified *a priori* (Table 1) as MC was not systematically larger than those of cultivars classified *a priori* as LC. Also, inhibitory effects of oat were not systematically different from those of other crops. Our results did not delineate clear groups, nor did they totally support earlier findings on the relative competitiveness of crop species. For example, Zimdahl (1980) concludes that barley is more competitive that oat and wheat. In our case, although the competitive effect of oat and wheat cannot be differentiated, we found no evidence that barley was more competitive. In contrast the contrary, oat was found to be more competitive than two-row barley with respect to some root characteristics and more competitive than six-row barley for some shoot and root characteristics (Table 2). While Moss (1985) reports differential competitive ability among two- and six-row barley cultivars, our data did not support such differences. This may indicate that the effects of crop and cultivar competitiveness on wild mustard cannot be determined within 3 weeks of emergence and that competition studies should be for a longer period. It may also suggest that growing conditions such as soil type, moisture availability or plant density may affect resource supply/demand ratio and play an important role when ranking crops and cultivars according to their competitive effects on weeds.

Competitive Responses

Competitive response is the ability to avoid being suppressed (Callaway 1992). After 3 weeks the presence of wild mustard had no significant effect on plant height but was slightly detrimental (6.7% decrease on the average) to the other above-ground growth characteristics (Table 3). This overall effect can be attributed mainly to two-row barley, which grew taller (8.6%) and produced more leaf area (16.3%) and above-ground biomass (25.8%) without wild mustard. In oat, above ground dry weight was also reduced (29.8%) by the presence of wild mustard.

The presence of wild mustard affected (9.9% increase on average) all below-ground growth characteristics (Table 3). This overall effect is mainly attributed to six-row barley for which length of small and large diameter roots, as well as root surface area, were larger (35.6% increase on average) with wild mustard. In wheat, root growth (length of large diameter roots) was also increased (29.8%) by the presence of wild mustard.

Although we were unable, initially, to detect a difference between two- and six-row barley in their impact on wild mustard, we detected a difference in their bility to avoid competition. The above-ground growth characteristics of two-row barley are sensitive to the presence of wild mustard, while the below-ground

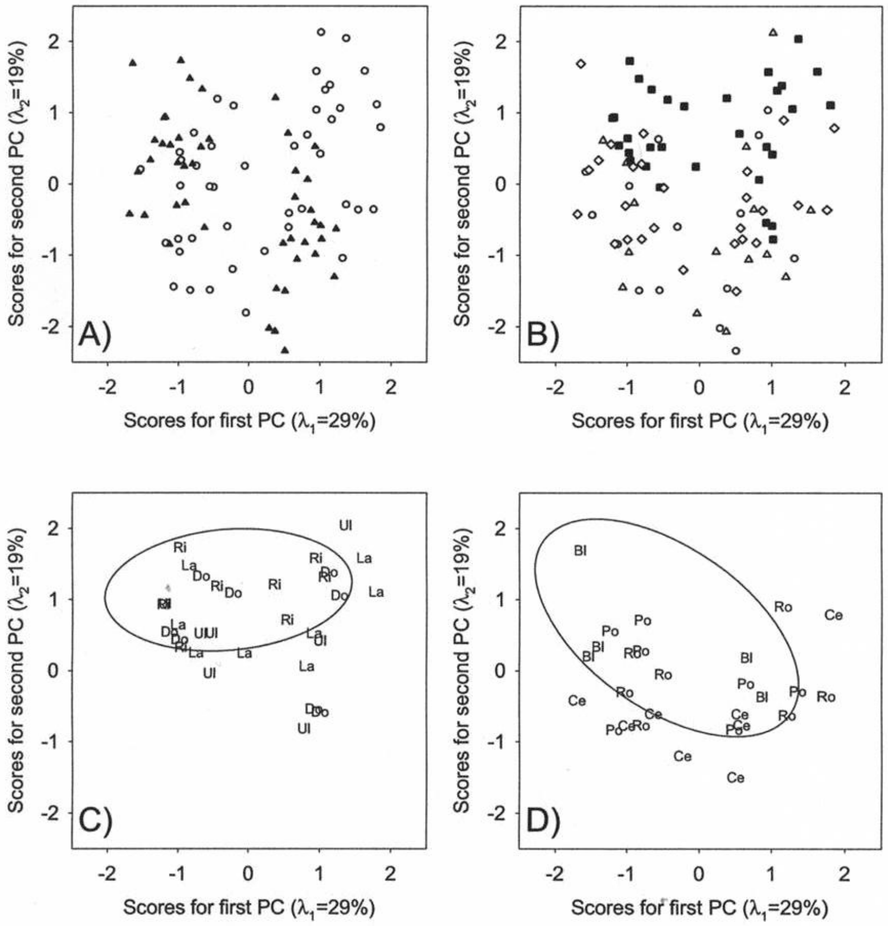

Figure 1. Results of a principal component analysis performed using crop and wild mustard traits and data for all crops and trials; graphs present the distribution of individual observations with respect to the first two principal components (explaining 48% of total variability): A) observations are identified according to trials, ○ for first trial and ▲ for second trial; B) observations are identified according to crops, ○ for two-row barley, Δ for six-row barley, ■ for oat, and ◊ for wheat; C) observations are identified according to oat cultivars, Laurent (La), Ultima (Ul), AC-Rigodon (Ri), and Donegal (Do); and D) observations are identified according to wheat cultivars, Celtic (Ce), Roblin (Ro), AC-Pollet (Po) and SS-Blomidon (Bl).

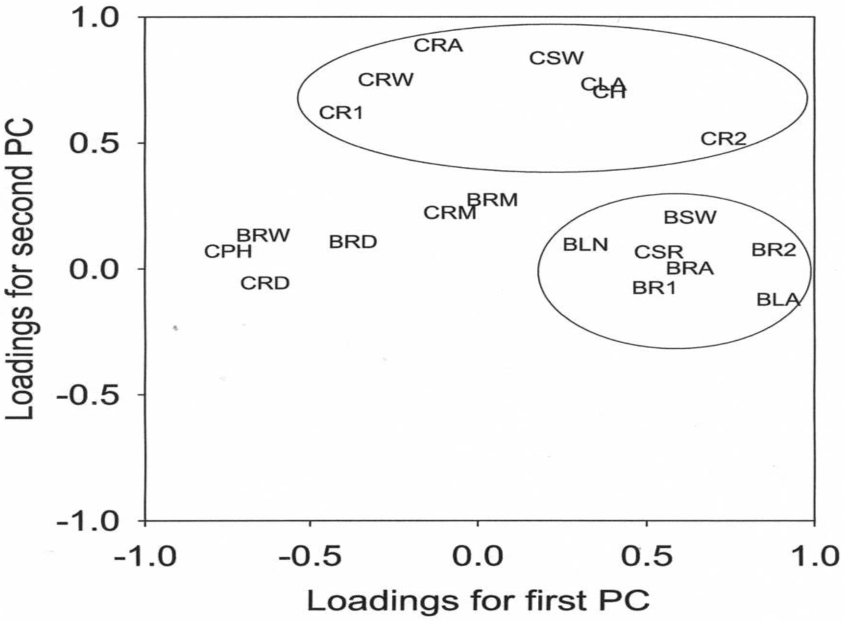

Figure 2**.** Results of a principal component analysis performed using crop and *Brassica* traits and data for all crops and trials; graph presents the distribution of traits with respect to the first two principal components (explaining 48% of total variability); traits are: *Brassica* leaf number (BLN), *Brassica* leaf area (BLA), *Brassica* shoot dry weight (BSW), *Brassica* root dry weight (BRW), *Brassica* rooting depth (BRD), *Brassica* root surface area (BRA), length of small diameter (< 1 mm) *Brassica* roots (BR1), length of large diameter (≥1 mm) *Brassica* roots (BR2), *Brassica* average root diameter (BRM), crop height (CH), crop leaf area (CLA), crop shoot dry weight (CSW), crop rooting depth (CRD), crop root dry weight (CRW), crop average root diameter (CRM), crop root surface area (CRA), length of small diameter (< 1 mm) crop roots (CR1), length of large diameter (≥ 1 mm) crop roots (CR2), crop net photosynthesis (CPH), and crop shoot to root ratio (CSR).

Table 2**.** Average number of leaves, leaf area, above ground dry weight (DW), length of small diameter (< 1 mm; cm plant^{-1}) roots, length of large diameter roots (≥1 mm; cm plant^{-1}), and root surface area of wild mustard grown for 3 weeks with and without competition from two-row barley, six-row barley, oat, and wheat cultivars.

Crop/Cultivar	# of leaves plant^{-1}	Leaf area cm^2 plant^{-1}	Above ground DW g plant^{-1}	Length of small diameter roots	Length of large diameter roots	Root surface area cm^{2}plant^{-1}
Two-row barley (mean)	4.58±0.41	27.85±0.33	81±21	903±286	94±72	120±40
Iona (Io)	4.56±0.29	28.37±0.35	83±18	939±357	107±87	126±47
Winthrop (Wi)	4.59±0.52	27.34±0.33	78±24	866±212	82±58	114±33
Contrast (Io vs Wi)[a]	NS[b]	NS	NS	NS	NS	NS
Six-row barley (mean)	4.58±0.58	31.37±0.33	85±22	956±300	111±94	134±47
Cadette (Ca)	4.72±0.77	33.05±0.3	89±26	1057±366	123±104	151±52
Chapais (Ch)	4.44±0.26	29.98±0.36	82±18	856±187	99±88	118±37
Contrast (Ca vs Ch)	NS	NS	NS	*	NS	*
Oat (mean)	4.59±0.39	25.47±0.4	76±22	803±275	91±73	108±38
Laurent (La)	4.84±0.27	26.07±0.45	80±18	944±313	106±94	125±43
Ultima (Ul)	4.44±0.26	26.01±0.38	77±20	892±254	84±67	116±37
AC-Rigodon (Ri)	4.38±0.38	24.03±0.46	74±20	617±175	81±63	88±27
Donegal (Do)	4.69±0.5	25.83±0.4	74±30	768±261	93±76	103±37
Contrast (La vs Ul)	*	NS	NS	NS	NS	NS
Contrast (Ri vs Do)	NS	NS	NS	NS	NS	NS
Contrast (Ri&Do vs La&Ul)	NS	NS	NS	**	NS	*
Wheat (mean)	4.66±0.45	27.27±0.36	81±27	839±284	104±96	117±47
Celtic (Ce)	4.75±0.33	26.41±0.37	80±29	899±393	113±122	126±67
Roblin (Ro)	4.94±0.26	30.94±0.38	91±20	962±238	123±102	135±41
AC-Pollet (Po)	4.59±0.48	26.85±0.32	77±25	791±279	105±101	110±46
SS-Blomidon (Bl)	4.38±0.55	25.19±0.42	75±33	686±103	70±51	95±17
Contrast (Ce vs Ro)	NS	*	NS	NS	NS	NS
Contrast (Bl vs Po)	NS	NS	NS	NS	NS	NS
rast (Bl,Po vs Ce,Ro)	**	NS	NS			

[a] Single degree of freedom comparisons.

growth of six-row barley was significantly different with or without presence of wild mustard. This may partly explain why six-row barley has been reported to be more competitive than two-row barley (Moss 1985).

We cannot explain why wild mustard appears to favor an increased root growth in six- row barley, and to a lesser extent, in wheat. According to Römer *et al*. (1988), mineral deficiencies (e.g., phosphorus) can stimulate root growth, but that is unlikely in this case as the growth media was regularly supplied with large amounts of Hoagland's nutrient solution. Also, no visual symptoms of mineral deficiency were observed in both trials of the experiment. Similarly, the possibility that exudates arising from cereal roots would stimulate wild mustard root growth is highly improbable as previous work demonstrated that cereal root exudates (same species and cultivars) significantly reduce wild mustard radicle growth (Baghestani *et al*., 1999). One may speculate that, in presence of wild mustard, these speciesmay show the capacity to avoid competition by extending their roots below the zone explored by wild mustard. In this study we did not specifically studied the occupation of below ground space by crop and wild mustard. However we collected data (not shown) on longest root length, which are not supportive of the latter hypothesis: in wild mustard longest root length averaged 57.0 cm; in six-row barley it reached 81.9 cm in weeded compartments and 80.2 cm in weed free compartments; in wheat it was 77.3 cm in weeded compartments and 74.0 cm in weed free compartments.

As the presence of wild mustard had a detrimental effect on the above-ground growth of some crops, but no adverse effects were noted on below-ground growth, shoot competition may precede root competition. In contrast, for soybean and common cocklebur (*Xanthium strumarium* L.), below-ground competition is reported to occur first (Bozsa & Oliver, 1990). We cannot explain this discrepancy, but we note that competition in our study was between a dicot plant and grass species while in Bozsa and Oliver (1990) competition was between two dicot species.

Table 3. Average plant height (ht), leaf area, above ground dry weight (DW), length of small diameter (< 1 mm; cm $plant^{-1}$) roots, length of large diameter (≥1 mm; cm $plant^{-1}$) area, and root dry weight, root surface area of two-row barley, six-row barley, oat, and wheat cultivars grown for 3 weeks with and without competition from wild mustard.

Crop/Cultivar	Plant ht cm	Leaf area cm^2 $plant^{-1}$	Above ground DW g $plant^{-1}$	Length of small diameter roots	Length of large diameter roots	Root surface area cm^2 $plant^{-1}$	Root DW g $plant^{-1}$
All crops with wild mustard	31.6±0.2	22.41±0.47	118±37	1391±298	131±86	221±58	77±28
All crops without wild mustard	32.2±0.2 23	86±0.47	127±39	1297±314	114±80	202±58	71±23
Contrast (with vs without)[a]	NS[b]	*	**	*	*	**	*
Two-row barley with wild mustard	26.7±0.2	18.2±0.33	91±30	1387±409	98±71	194±69	60±19
Two-row barley without wild mustard	29.2±0.2	21.76±0.49	123±33	1424±358	113±86	199±60	60±22
Contrast (with vs without)	*	**	***	NS	NS	NS	NS
Six-row barley with wild mustard	26.3±0.2	20.56±0.36	96±29	1246±281	119±87	196±59	62±20
Six-row barley without wild mustard	26.5±0.1	19.37±0.25	89±19	984±173	80±52	149±37	50±14

Continue next page

Table3. continue

Crop/Cultivar	Plant ht cm	Leaf area cm^2 $plant^{-1}$	Above ground DW g $plant^{-1}$	Length of small diameter roots	Length of large diameter roots	Root surface area cm^2 $plant^{-1}$	Root DW g $plant^{-1}$
Contrast (with vs without)	NS	NS	NS	**	**	**	NS
Oat with wild mustard	37.6±0.1	31.8±0.29	146±30	1369±239	163±86	250±43	90±24
Oat without wild mustard	37.6±0.1	34.13±0.37	158±42	1294±294	153±97	235±62	84±24
Contrast (with vs without)	NS	NS	*	NS	NS	NS	NS
Wheat with wild mustard	31.5±0.2	18.23±0.42	115±34	1490±272	121±88	219±53	80±33
Wheat without wild mustard	31.9±0.1	19.32±0.3	118±23	1399±26	4 93±51	197±38	73±17
Contrast (with vs without)	NS	NS	NS	NS	**	NS	NS

[a] Single degree of freedom comparisons.
[b] NS, *, **, and *** stand for not significant, and significant at the 5, 1, and 0.1% levels, respectively.

Differential Growth of Crop Kind and Cultivar with Weed Competition.
In the presence of wild mustard, oat growth (as measured by plant height, leaf area, above and below-ground dry weight, length of large diameter roots and root surface area) was more than that of two-row barley, six-row barley, and wheat (Table 4). Length of small diameter roots is the only diverging trait as it did not differ significantly between oat and two-row barley. Also, the length of small diameter roots is larger for wheat than for oat.

Growth of two-row barley, oat, and wheat cultivars classified *a priori* as MC was generally larger than that of LC cultivars (Table 4). However, growth of six-row barley 'Cadette' and 'Chapais' did not differ. A few erratic differences in some growth characteristics were also observed between LC oat cultivars 'Laurent' and 'Ultima' and LC wheat cultivars 'Celtic' and 'Roblin'. Among MC oat cultivars, 'AC-Rigodon' had higher values for two of the seven growth traits, while among MC wheat cultivars, 'SS-Blomidon' had higher values for four of the seven growth traits.

In summary, all cereals can reduce wild mustard growth but two- and six-row barley were less efficient than oat for some of the growth characteristics measured. For two-row barley, this corresponded to an inability to avoid above-ground competition (competitive response) from wild mustard. For six-row barley, however, there seems to be no link between competitive effect and competitive response.

In terms of cereal growth in the presence of wild mustard, oat produced significantly more above- and below-ground growth than the other cereals. This may partly explain the relative success of this crop (compared with two- and six-row barley) in terms of competitive effects. However, this does not explain the competitive effects and competitive responses among the other crops studied. Oat and wheat, for example, had a similar competitive pattern but a different growth pattern.

Within species, the competitive pattern and growth patterns are inconsistent for barley, but consistent for oat and wheat. For two-row barley, the MC cultivar 'Winthrop' produced more biomass than the LC cultivar 'Iona', but both had

Table 4. Average plant height (ht), leaf area, above ground dry weight (DW), length of small diameter (< 1 mm; cm plant^{-1}) roots, length of large diameter (≥1 mm; cm plant^{-1}) roots, root surface area, and root dry wt of two-row barley, six-row barley, oat, and wheat cultivars grown for 3 weeks in competition with wild mustard.

Crop/Cultivar	Plant ht cm	Leaf area cm^{2}plant^{-1}	Above ground DW g plant^{-1}	Length of small diameter roots	Length of Large diameter roots	Root surface area cm^{2}plant^{-1}	Root dry wt g plant^{-1}
Two-row barley (mean)	26.7±0.2 18	2.00±0.33	91±30	1387±409	98±71	194±69	60±19
Iona (Io)	24.5±0.2 17	28.00±0.29	76±25	1258±363	80±47	174±55	58±23
Winthrop (Wi)	29.0±0.100	19.18±0.38	106±30	1516±435	117±88	215±79	62±16
Contrast (Io vs Wi)[a]	***[b]	**	**	***	NS	**	NS
Six-row barley (mean)	26.3±0.2	20.56±0.36	96±29	1246±281	119±87	196±59	62±20
Cadette (Ca)	27.2±0.2	21.49±0.32	95±28	1280±288	125±101	202±65	63±20
Chapais (Ch)	25.4±0.1	19.67±0.42	97±32	1211±289	113±77	191±56	62±21
Contrast (Ca vs Ch)	NS	NS	NS	NS	NS	NS	NS
Oat (mean)	37.6±0.1	31.8±0.29	146±30	1369±239	163±86	250±43	90±24
Laurent (La)	40.7±0.1	30.71±0.46	155±26	1195±194	52±85	227±40	92±17
Ultima (Ul)	35.7±0.1	30.39±0.30	130±32	1402±258	157±92	253±43	85±18
AC-Rigodon (Ri)	37.7±0.1	34.47±0.21	155±28	1533±166	176±92	271±34	104±37
Donegal (Do)	36.5±0.1	31.77±0.21	143±31	1348±236	164±90	250±48	79±18
Contrast (La vs Ul)	**	NS	***	**	NS	NS	*
Contrast (Ri vs Do)	NS	NS	NS	*	NS	NS	*
Contrast (Ri&Do vs La&Ul)	NS	*	NS	*	**	**	NS

Continue next page

Table 4. Continue

Crop/Cultivar	Plant ht cm	Leaf area $cm^2 plant^{-1}$	Above ground DW g $plant^{-1}$	Length of small diameter roots	Length of Large diameter roots	Root surface area $cm^2 plant^{-1}$	Root dry wt g $plant^{-1}$
Wheat (mean)	31.5±0.2	18.23±0.42	115±34	1490±272	121±88	219±53	80±33
Celtic (Ce)	28.9±0.2	14.27±0.32	92±25	1375±250	99±76	193±41	68±18
Roblin (Ro)	30.4±0.1	17.14±0.28	106±22	1439±278	112±88	209±49	71±11
AC-Pollet (Po)	33.3±0.1	18.79±0.31	115±24	1514±242	115±70	221±44	79±19
SS-Blomidon (Bl)	33.8±0.2	23.93±0.55	147±45	1652±291	163±120	259±66	102±59
Contrast (Ce vs Ro)	NS	*	NS	NS	NS	NS	NS
Contrast (Bl vs Po)	NS	**	*	NS	*	NS	*
Contrast (Bl&Po vs Ce&Ro)	**	***	***	*	*	*	**
Contrast (Oat vs two-row barley)	***	***	***	NS	***	***	
Contrast (Oat vs six-row barley)	***	***	***	***	***	***	***
Contrast (Oat vs wheat)	***	***	***	**	***	***	

[a] Single degree of freedom comparisons selected after the principal component analysis.
[b] NS, *, **, and *** stand for not significant, and significant at the 5, 1, and 0.1% levels, respectively

similar competitive effects. For six-row barley, above- and below-ground growth of the MC cultivar 'Chapais' and the LC cultivar 'Cadette' were similar, but 'Chapais' had a greater competitive effect on wild mustard growth. For oat and wheat, the MC cultivars produced more above- and below-ground growth than the LC cultivars and also had a greater competitive effect on wild mustard growth.

These results do not show a universal link between the shoot and root characteristics of 3-week-old seedlings of individual cereal lines and their ability to compete with wild mustard. In the case of two- and six-row barley, the evidence in support of such a link is inconclusive. For oat and wheat, a link can be established. Oat cultivars that produced more leaf area, root length, and root surface area were identified as being more competitive than the other cultivars. For wheat, cultivars that grew taller, produced more leaf area and above-ground biomass, produced longer roots, and more root surface area and below-ground biomass were identified as being more competitive than the other cultivars. Based on root and shoot characteristics, these results suggest that it may be possible to select oat and wheat cultivars for greater competitive ability against wild mustard. The use of competitive cereal cultivars may improve weed control and reduce herbicide use in cereal production systems. We suggest that breeders use this information to compare oat and wheat lines for evaluating competition with weeds.

REFERENCES:

Arnone III, J.A. & Kestenholz, C. 1997. Root competition and elevated CO2: effects on seedling growth in *Linum usitatissimum* populations & *Linim-siliene cretica* mixtures. *Functtional Ecology* **11**: 209-214.

Baghestani, A., Lemieux, C., Leroux, G.D, Baziramakenga, R. & Simard, R.R. 1999. Determination of allelochemicals in spring cereal cultivars of different competitiveness. *Weed Science* **47**: 498-504.

Bozsa, R.C. & Oliver, L.R. 1990. Competitive mechanisms of common cocklebur (*Xanthium strumarium*) and soybean (*Glycine max*) during seedling growth. Weed Science **38**: 34-350.

Callaway, M.B. 1992. A compendium of crop varietal tolerance to weeds. *Amrican Journal of Alternative Agriculture* **7**: 169-180.

Challaiah, R.E., Burnside, O.C., Wicks G.A. & Johnson V.A. 1986. Competition between winter wheat (*Triticum aestivum*) cultivars and downy brome (*Bromus tectorum*). *Weed Science* **34**: 689-693.

Christensen, S. 1995. Weed suppression ability of spring barley varieties. *Weed Reserach* **35**: 241-247.

Dahl, G.K., Dexter A.G. & Nalewaja, J.D. 1982. Wild mustard competition and control in wheat. In: Proceedings of North Central Weed Control Conference (NCWCC), 7-9 Dec., 1982. Indianapolis, Indiana **37**: 23–23.

Dunan, C.M., & Zimdahl, R.L. 1991. Competitive ability of wild oat (*Avena fatua*) and barley (*Hordeum vulgare*). *Weed Science* **39**: 558-563.

Evetts, L.L., & Burnside, O.C. 1973. Early root & shoot development of nine plant species. *Weed Science* **21**: 289-291.

Grundy, A.C., & Froud-Williams, R.J. 1993. The use of cultivar, crop seed rate and nitrogen level for the suppression of weeds in winter wheat. Proceedings of Brighton Crop Protection Conference–Weeds. pp 997-1002.

Hackett, C. 1969. A study of the root system of barley. II. Relationships between root dimensions and nutrient uptake. *New Phytology* **68**: 1023-1030.

Hallberg, G.R. 1987. Agricultural chemicals in ground water: extent and implication. *Amrican Journal of Alternative Agriculture* **2**: 3-15.

Holm, L.J., Doll., Holm, E., Pancho, J. & Herberger, J. 1997. World Weeds: Natural 370. Histories and Distribution. John Wiley & Sons. 1129 p.

James, K.L., Banks, P.A. & Karnok, K.J. 1988. Interference of soyabean, Glycine max, cultivars with Sicklepod, Cassia obtusifolia. *Weed Technology* **2**: 404-409.

Liebman, M. & Robichaux, H. 1990. Competition by barley and pea against mustard: effects on resource acquisition, photosynthesis and yield. *Agricultural Ecosystem*. *Environment* **31**:155-172.

Mian, M.A.R., Nafziger, E.D., Kolb, F.L., & Teyker, R.H. 1993. Root growth of wheat genotypes in hydroponic culture and in the greenhouse under different soil moisture regimes. *Crop Science* **33**: 283-286.

Mian, M.A.R., Nafziger, E.D. Kolb, F.L. & Teyker, R.H. 1994. Root size and distribution of field-grown wheat genotypes. *Crop Science* **34**: 810-812. 381

Monks, D. W., Oliver, L. R. & Bozsa, R. C. 1988. Seedling growth of soybeans (*Glycine max*) and selected weeds. *Weed Science* **36**: 167-171.

Moss, S. R. 1985. The influence of crop variety & seed rate on Alopecurus 384

myosuroides competition in winter cereals. British Crop Protection Conference– Weeds. 7A- 5: 701–708. 386

Pavlychenko, T.K. 1937. Quantitative study of the entire root systems of weed and crop plants under field conditions. *Ecology* **18**: 62-79.

Preradov-Odobasic, A. 1997. Évaluation des cultivars de céréales de printemps à l'égard desmauvaises herbes. Mémoire de maîtrise. Département de phytologie, Université Laval, Canada. 86 p.

Richards, M.C. & Davies, D.H.K. 1991. Potential for reducing herbicide inputs/rates with more competitive cereal cultivars. Proceedings of Brighton Crop Protection Conference-Weeds. 1233–1240.

Römer, W., Augustin, J. & Schiling, G. 1988. The relationship between phosphate absorption and root length in nine wheat cultivars. Plant & Soil 111: 199-201.

Rooney, J. M. 1991. Influence of growth form of *Avena fatua* L., on the growth and yield of *Triticum aestivum* L. *Annual Applied Biology* **118**: 411-416.

SAS Institute Inc. 1989. SAS/STATS® User's guide, Version 6, Fourth Edition, Volume 1. 943 p.

Steel, R.G.D. & Torrie, J. H. 1980. Principles and procedures of statistics. A biometrical approach, 2nd Ed. McGraw-Hill Inc. New York. 633 p.

Tacq, J. 1997. Multivariate analysis techniques in social science research. SAGE Publications Ltd., London. 411 p.

Verschwele, A. & Niemann, P. 1994. Indirect weed control by selection of wheat cultivars. In: Maîtrise des Adventices par Voie Non Chimique. Communications de la quatrième conférence internationale (J.M. Thomas, ed.). I.F.O.A.M., 5–9 Juillet 4.993. Dijon, France. Pp. 269-273.

Wang, X. & Below, F.E. 1992. Root growth, nitrogen uptake, and tillering of wheat induced by mixed-nitrogen source. *Crop Science* **32**: 997-1002.

Warwick, S.I., Beckie, H.J., Thomas A.G. & McDonald T. 2000. The biology of Canadian weeds. 8. *Sinapis arvensis* L. (updated). *Canadian Journal of Plant Science* **55**: 171–183.

Wicks G. A., Ramsel, R. E., Nordquist, P. T., Schmidt, J. W. & Challaiah, O. C. 1986. Impact of wheat cultivars on establishment and suppression of summer annual weeds. *Agronomy Journal* **78**: 59-62.

Wilson, J. B. 1988. Shoot competition & root competition. *Journal of Applied Ecology* **25**: 279-296.

Wortmann, C.S. 1993. Contribution of bean morphological characteristics to weed suppression. *Agronomy Journal* **85**: 840-843.

Zimdahl, R.L. 1980. Weed-crop competition: a review. International Plant Protection Center. Oregon State University. USA. 195 p.