Pak. J. Weed Sci. Res. 12(3): 131-144, 2006.

IRANIAN WINTER WHEAT'S (*Triticum aestivum* L.) INTERFERENCE WITH WEEDS: II. GROWTH ANALYSIS

Mohammad Ali Baghestani[1], Eskandar Zand and Saeid Soufizadeh

ABSTRACT

A two year experiment was conducted during 2000 to 2002, at Plant Pest and Disease Research Institute, Karaj (35° 59′ N 52° 60′ E, 1160 masl), Iran to identify the morphological and physiological characteristics which contribute to more competitive ability of Iranian winter wheat genotypes against weeds. Six more and less competitive wheat genotypes were studied under competition with Goldbachia laevigata and Avena ludoviciana. Total tiller m^{-2}, plant height, leaf area index (LAI), total dry matter (TDM), crop growth rate (CGR), and relative growth rate (RGR) in different genotypes were studied. Results indicated that 6618 as the most competitive genotype produced significantly higher number of tillers m^{-2} under weed infested condition compared with other genotypes in 2000-2001. In this year, the lowest number of tillers belonged to M-75-5 which was ranked as the least competitive genotype. 6618 was also ranked first among all genotypes for plant height, LAI at zadoks 52-64, and flag leaf area. In 2001-2002, 6618 had the tallest plant height under weed infested condition, while the less competitive genotype M-75-5 possessed the shortest height. 6618 possessed greater LAI and TDM under both, the weed free and the weed infested conditions compared with M-75-5. CGR and RGR of 6618 were much larger than that of M-75-5 which agrees with greater LAI of this genotype compared with M-75-5. Totally, growth analysis showed that taller plant height, greater LAI, CGR, and TDM are among the traits that confer competitiveness in wheat.

Key words: Wheat competitive ability, weed competition, genotypes, Crop growth rate, Tiller number.

INTRODUCTION

Weeds can result in high yield losses in cereal crop production systems, particularly without the use of herbicides or lack of weed control because of herbicide resistance (Powles *et al.* 1997). One of the significant goals of Integrated Weed Management (IWM) systems is using crop varieties with high competitiveness against weeds to cope with these problems (Baghestani *et al.* 2005). Crop varieties differ substantially in their ability to compete with weeds (Callaway, 1992). Yield losses from weed competition can be reduced if crop competitiveness is improved by methods such as fertilizer placement, a varied crop rotation and by using varieties with strong competitiveness (Jordan, 1993). Thus, identification of those traits which enhance crop

[1]Department of Weed Research, Plant Pest and Disease Research Institute, P.O. Box 19395-1454, Tehran, Iran
Corresponding author E-mail address: baghestani@hotmail.com (M.A. Baghestani)

competitive ability against weeds, play an important role in successful management of weeds in crops (Olesen *et al.* 2004).

Planting a more competitive cultivar has been suggested as a cultural practice to suppress weed growth. However, few studies have been conducted to determine the competitiveness of winter wheat cultivars or to identify wheat characteristics that are important in enhancing competitiveness (Ogg and Seefeldt, 1999). In fact, before a more competitive winter wheat cultivar can be developed, plant breeders need to know what combination of plant traits will make a cultivar more competitive against weeds (Ogg and Seefeldt, 1999). Plant growth analysis can serve as an indicator of potential competitive ability among crops and weeds (Radosevich and Holt, 1984; Rejmanek *et al.* 1989; Tanji *et al.* 1997; Olesen *et al.* 2004). Roush and Radosevich (1985) found that the competitive hierarchy suggested by the growth analysis parameters was consistent with the hierarchy of plant species obtained in the competition enhancement. Characteristics commonly identified to make crops more competitive include rapid germination, early above ground growth, rapid leaf area and canopy establishment, large leaf area development and duration, high tillering capacity and greater plant height (Christensen, 1995; Lemerle *et al.* 1996; Pester *et al.* 1999; Lemerle *et al.* 2001). The morphological and physiological traits of a strongly competitive crop will enable it to capture resources from a weed, or utilize resources more efficiently, than a poor competitive crop (Lemerle *et al.* 2001). For example plant growth characteristics that increase light interception by the crop canopy generally increase crop competitiveness with weeds (Wang *et al.*, 2004). Kropff *et al.* (1992) found that the leaf area of eastern black night shade (*Solanum ptycanthum* Dun.) was the important determinant of competitive outcome when grown with tomato (*Lycoprsicon esculentum* Mill.). Callaway and Forcella (1993) developed a new soybean (*Glycine max* L. Merrill) genotype with higher leaf area production that was better able to suppress weed growth. Hamblin and Rowell (1975) hypothesized that a competitive ideotype, which is taller than its neighbors, tillers more, and with a horizontal leaf display will yield well in a mixed community and poorly in monoculture. In contrast, a weakly competitive crop ideotype (short, low tillering, erect leaf display and high harvest index) would optimize grain yield in monoculture.

Considerable research has been undertaken on competitive ability of wheat cultivars, due to the economic importance of the crop and diversity of its varieties grown throughout the world. However, few studies have been conducted to determine the competitiveness of Iranian winter wheat cultivars or to identify wheat characteristics that are important in enhancing competitiveness against weeds. Our objective was to identify the morphological and physiological characteristics which contribute to more competitive ability of Iranian wheat genotypes against weeds.

MATERIALS AND METHODS

A two year experiment was conducted during 2000 to 2002, at Plant Pest and Disease Research Institute, Karaj (35° 59′ N 52° 60′ E, 1160 masl), Iran. Soil type was sandy clay. Each year the experimental field was plowed and followed by two disking in the fall to prepare the seedbed for planting. The mean annual rainfall of this zone is 250mm and the climate is arid. Long term mean, maximum and minimum annual temperatures are 13.7, 41 and −21.7°C, respectively. All of the experimental fields were fallowed during previous year. Plots were fertilized with 150 kg ha^{-1} ammonium phosphate and 50 kg ha^{-1} potassium sulfate prior to seeding. Details on nitrogen fertilizer application, wheat seeding, and planting pattern are provided in a preceding paper (Baghestani *et al.* 2006).

The experiments were conducted as a randomized complete block design with factorial arrangement of treatments and four replications. Experimental factors were six wheat genotypes each studied under competition with *Goldbachia laevigata*, and *Avena ludoviciana*. *A. ludoviciana* and *G. laevigata* seeds were sown simultaneously with wheat and later thinned to 50 and 30 plants m^{-2}. Seed viability of *A. ludoviciana* and *G. laevigata* were 32 and 80%, respectively. Planting dates were September 8 in 2000, and September 5 in 2001. During the growing season, all weed species except *G. laevigata* and *A. ludoviciana* were hand weeded.

In 2000-2001, two samples were taken during the wheat growing period on March 13 (Zadoks 20 to 22) and April 24 (Zadoks 52 to 64) 2001 using two 0.25m^2 quadrates. Wheat height was measured as distance between root crown and the first fully expanded leaf. Leaf area of the whole crop and flag leaf were measured in the second sampling only with a leaf area meter (LI-3100A, LiCor Inc., Lincoln, Nebraska, USA). Total number of wheat tillers was also counted in the second sampling.

In 2001-2002, five samples were taken on March 18 (Zadoks 20 to 25), April 3 (Zadoks 35 to 40), April 18 (Zadoks 49 to 55), May 3 (Zadoks 59 to 65) and May 18 (Zadoks 73 to 83) 2002. Samples were taken from each plot using two 0.25m^2 quadrates. Plant height and leaf area were measured at each sampling as in 2000-2001. Harvested materials were oven dried at 75°C for 48h and weighed.

Plant heights were fitted with a logistic equation (Christensen, 1995)

$$H = \frac{H_m}{(1 + \exp(a - bx))} \quad (1)$$

Where *H*, is wheat height, H_m is the maximum attainable height, *x* is days after planting, and *a* and *b* are constants. In this equation the ratio *a/b* defines the point in time at which one half of maximum height is attained.

To obtain growth physiological indices, the means of the total dry matter (*TDM*) data (*W*) were transformed to natural logarithms to obtain homogeneity of errors (Steel and Torrie, 1980) and then were regressed against time (as days after planting; DAP) (Eq. 2). A quadratic polynomial function was fitted to describe the relationships between plant dry matter data and time. Relative growth rate (*RGR*) was calculated as the first derivative of the *TDM* function (Eq. 3). Crop growth rate (*CGR*) was calculated by multiplying *TDM* by *RGR* (Eq. 4).

$$TDM = \exp(f_w(t)) \quad (2)$$

$$RGR = f_w'(t) \quad (3)$$

$$CGR = TDM \times RGR \quad (4)$$

To describe LAI a quadratic polynomial function was used for leaf area data. Analysis of variance was performed on the data of 2000-2001 using PROC GLM procedure in SAS software (SAS Institute, 1996). Means were separated using Duncan multiple range test (DMRT) set at P=0.05. Where the interaction between the two experimental factors was not significant data were analyzed separately by each factor. The curves in 2001-2002 were fitted with the EXCEL software.

RESULTS AND DISCUSSION

1. 2000-2001 experiment

Significant differences between genotypes were found at each sampling for all traits (Table-1). Results indicated that 6618 genotype produced significantly higher number of tillers under weed infested condition compared with other genotypes. The lowest number of tillers belonged to M-75-5 genotype. 6618 was also ranked first among all genotypes for plant height, LAI at zadoks 52-64, and flag leaf area. Since competitive index (CI) of a cultivar has a linear relationship with its grain yield, so high CI in 6618 and low CI in M-75-5 can be attributed to differences in these traits. Higher number of tiller reduces light quantity and quality beneath the crop canopy and thereby reducing weed growth, and that result in higher grain yield of a crop under weed infestation (Blackshaw, 1994). Grundy *et al.* (1993) showed that high number of tillers per unit area resulted in more shading on weeds and that resulting in weed suppression. Greater LAI of 6618 genotype can be attributed to its high tillering ability. Taller plant height of 6618 has also contributed to its competitiveness. Both, greater LAI and taller height of 6618 have resulted in more shading on weeds, thus suppressed weed growth. The importance assigned to tillering and heights sometimes varied by study. In the studies of Garrity *et al.* (1992) and Gibson *et al.* (2001), leaf area was important but tillering ability was not. Tillering ability is somewhat difficult to understand as a competitiveness trait, since it may both cause and effect: greater growth probably increases the potential to produce tillers, but increased tillering may contribute to greater growth (Caton *et al.* 2003). Greater flag leaf area of 6618 guaranteed an effective grain filling in late season in this genotype. Although taller height at zadoks 20-22 and greater LAI and flag leaf area compared with other genotypes, M-75-5 ranked as a less competitive genotype in the preceding paper (Baghestani *et al.* 2006). In contrast, M-75-15 had the least LAI and height at zadoks 52-64 and 20-22, respectively, nonetheless was not ranked as a less competitive genotype in our previous study. Thus, greater amounts of these traits likely confer an advantage but additional combinations of multiple traits probably determine overall competitiveness. No single growth trait guaranteed increased productivity here. Generally, preferences in above traits in 6618 probably contribute to suppression of weed growth for two reasons. First, leaf area, height, and tillering ability are important factors in several previous studies (Lemerle *et al.* 1996; Pester *et al.* 1999; Lemerle *et al.* 2001). Second, when resources are limiting in competition, an increase in resource capture by the crop must reduce resource capture by the crop. Both, high tillering ability and LAI will result in more resource capture by the crop. Tiller production ability was also investigated separately in 6618 and M-75-5, as the most and least competitive genotypes, under competition with *G. laevigata* and *A. ludoviciana* (Fig. 1). As observed, tillering ability of 6618 genotype under weed free condition was much higher than that of M-75-5, which agrees with

Table-1. Total tiller number m^{-2}, plant height (cm) at Zadoks 20-22 and 52-64, wheat leaf area index and flag leaf area at Zadoks 54-64 in 2000-2001.

Genotypes	Total tillers m^{-2}	Plant height (cm) Zadoks 20-22	Plant height (cm) Zadoks 52-64	LAI	Flag leaf area (cm^2)
6618	859a	75a	110a	3.5a	6.7a
M-75-13	588bc	69b	100b	1.9bdc	5.6abc
M-75-15	665bc	62d	91d	1.1d	4.9bc
Alamot	665b	69bc	107ab	1.5cd	4.7c
Qafqaz	583c	74ab	99bc	2.6ab	6.17ab
M-75-5	582c	63dc	90d	2.3bc	5.5abc

*In each column, means followed with same letter do not differ by Duncan's multiple range test at $\alpha_{0.05}$.

2. 2001-2002 experiment

higher potential of this genotype in competing with weeds. The genotype 6618 produced higher number of tillers compared with M-75-5 under both weed species infestation. Also, results indicated that *A. ludoviciana* was more competitive than *G. laevigata* because it caused higher reduction in tiller production in wheat.

In this experiment, at first means over all wheat genotypes for LAI, TDM, CGR, and RGR are compared with each other under weed free, *G. laevigata*, and *A. ludoviciana* infestation. Then, similar comparisons were made between 6618 and M-75-5 genotypes as the most and least competitive genotypes to identify morphological and physiological traits contributing wheat competitiveness.

Plant height

Wheat plants height variation during the growing season is presented in Fig. 2. As it is observed, the more competitive genotype 6618 had the tallest plant height under weed infested condition, while the less competitive genotype M-75-5 possessed the shortest height. Study on wheat height under weed free condition indicates that 6618 was not the tallest genotype. This shows that 6618 was able to increase its height in competition with weeds which can be served as one of the important traits contributed to its more competitiveness compared with other genotypes. In fact, taller height of 6618 had caused it intercept more intact radiation. On the other hand, M-75-5 always had a plant height around 80cm under all conditions. As Blackshaw (1994) stated, greater plant height increases the crop resource capture especially radiation and that result in the expense of that of the weeds. It is also concluded that 6618 possessed similar plant height under both weed species infestation which shows this trait was not affected by weed species

Leaf area index

Leaf area index during the growing season is presented in Fig. 3. Wheats growing under weed free condition had larger LAI than those under weed infested condition

The reduction in this trait under weedy condition is due to competitive effect of weeds for resources, and that result in reduction in wheat growth. Wheat LAI under *G. laevigata* infestation was also lower than that under *A. ludoviciana* infestation.

6618 possessed greater LAI under both, the weed free and the weed infested conditions compared with M-75-5 (Fig. 4). Results show that this genotype had more potential in leaf production compared with M-75-5. In fact, greater LAI in 6618 has increased the crop resource capture at the expense of that of the weeds, in particular by reducing light quantity beneath the crop canopy and thereby reducing weed growth. Thus, as in many other studies, it is concluded that greater LAI is one of the most important contributing factors increasing crop competitiveness against weeds. As observed in Fig. 4, 6618 LAI decreased sooner under competition with *A. ludoviciana* than *G. laevigata*. The more negative effect of *A. ludoviciana* on wheat LAI compared with that of *G. laevigata* can be attributed to more severe competition between the crop and this weed because both belongs to similar plant family and thus have more resource demand in common. Both genotypes stayed green for a longer period under competition with *G. laevigata* compared with *A. ludoviciana*. This resulted in longer leaf area duration and higher grain yield of both genotypes under *G. laevigata* infestation.

Total dry matter

Wheat accumulated more plant dry biomass under weed free condition, competition with *A. ludoviciana*, and *G. laevigata*, respectively (Fig. 5). Contrary to the results on wheat LAI, however, *A. ludoviciana* was less inhibitory on wheat TDM compared with *G. laevigata*. The total plant dry biomass did not differ between the weed free and weedy treatments till 130 days after sowing (DAS), while from 130 DAS through the remainder of the season, the magnitude of the difference increased. This observation shows that competition will not commence early in the season until resources availability become limited due to increase in crop demand.

6618 accumulated more plant dry biomass throughout the growing period under weed free and *A. ludoviciana* infested conditions except early in the season (Fig. 6). During this period M-75-5 accumulated more biomass than 6618 under all conditions. Higher dry matter accumulation in 6618 can be attributed to its greater LAI, and that result in more light capture and assimilate production by the crop. Caton *et al.* (2003) stated that leaf area was the most important factor affecting rice dry matter. Garrity *et al.* (1992) found that tiller density, maximum plant height, and aboveground dry biomass are among the important traits contributing to rice competitiveness. Although possessing smaller LAI, the total dry biomass of *A. ludoviciana* infested plots in both genotypes was higher than that in *G. laevigata* infested plots. This may be attributed to more negative effect of *G. laevigata* on wheat canopy characteristics like leaf display and vertical leaf area distribution. The results also indicate that TDM of 6618 under *G. laevigata* infestation peaked later than the TDM of M-75-5. This shows that M-75-5 plants growing under *G. laevigata* infestation were delayed relative to the 6618.

Crop growth rate and Relative growth rate

Wheat CGR and RGR over the whole sampling period are presented in Fig. 7-10. As observed, CGR and RGR show similar variation among different treatments. Wheat had larger CGR and RGR in *A. ludoviciana* infested plots than *G. laevigata* infested plots (Fig. 7 & 9). As shown in Fig. 8 & 10, CGR and RGR of competitive genotype 6618 were much larger than that of M-75-5 which agrees with greater LAI of 6618 compared with M-75-5. But, an inverse relationship was found in 6618 between *A. ludoviciana* and *G. laevigata* infestation conditions for LAI, and CGR and RGR. 6618 under *G. laevigata* infestation had greater LAI but it possessed lower CGR, RGR and ultimately TDM, while under *A. ludoviciana* infestation the relationship was vice versa. Because 6618 height between these two conditions was similar, thus it can be concluded that greater LAI in

6618 under *G. laevigata* infestation has resulted in more shading of leaves on each other that may be related to the possible effect of *G. laevigata* on this genotype canopy architecture.

In M-75-5, wheat CGR and RGR were greater in competition with *G. laevigata* than *A. ludoviciana*. This advantage was due to greater LAI of M-75-5 under *G. laevigata* infestation. Wang *et al.* (2004) stated that plant growth characteristics that increase light interception by the crop canopy generally increase crop competitiveness with weeds. It is obviously seen that the role of different traits in competitiveness of a crop may vary between genotypes. While greater LAI in M-75-5 under weed infestation has been resulted in larger CGR and RGR, an inverse relationship was observed in 6618. This shows that other traits like leaf angle, leaf display and leaf vertical distribution may play an important role in determining genotype competitiveness.

Totally, growth analysis showed that taller plant height, greater LAI, CGR, and TDM are among the traits that confer competitiveness in wheat.

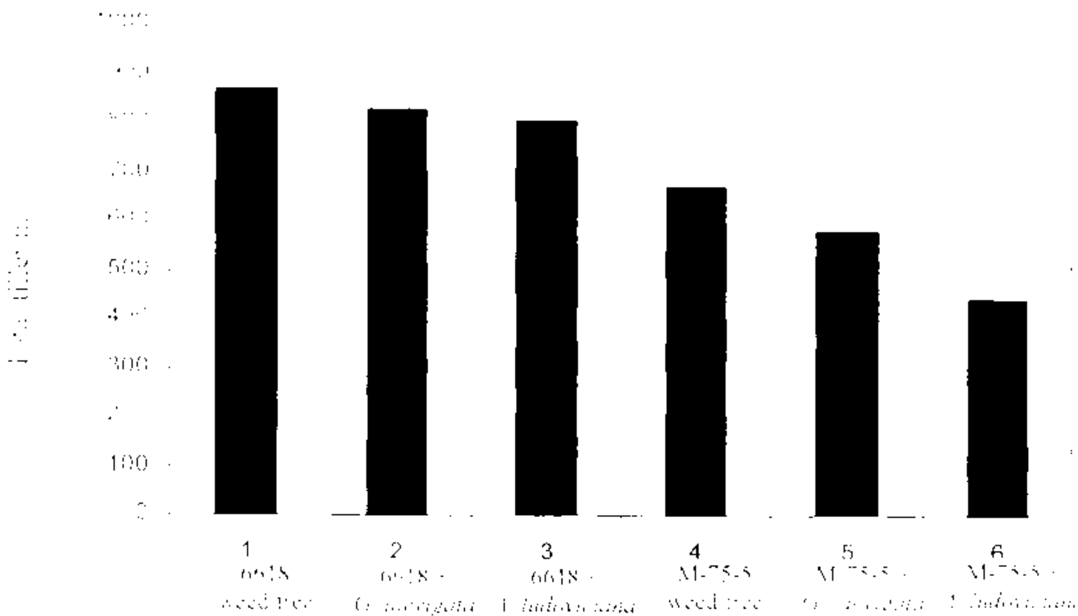

Fig. 1. Wheat total tillers m^{-2} of 6618 and M-75-5 genotypes at Zadoks 52-64 under weed free and *A. ludoviciana* and *G. laevigata* infested conditions in 2000-2001.

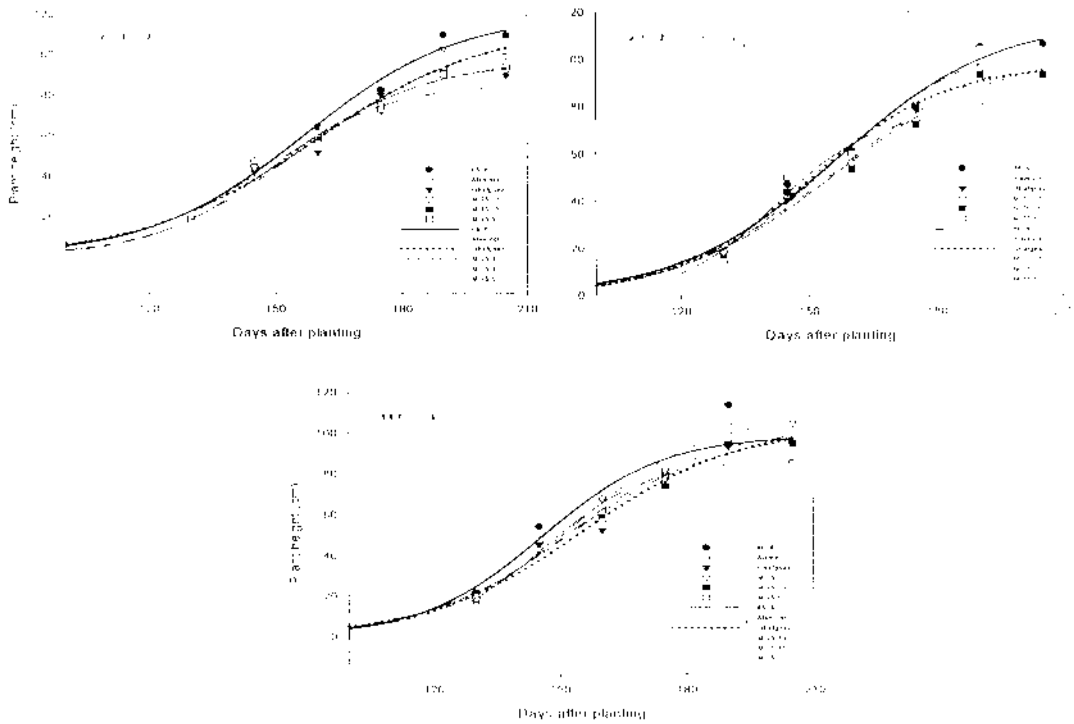

Fig. 2. Plant height of different wheat genotypes over the entire growing period under weed free, *A. ludoviciana* and *G. laevigata* infested conditions in 2001-2002.

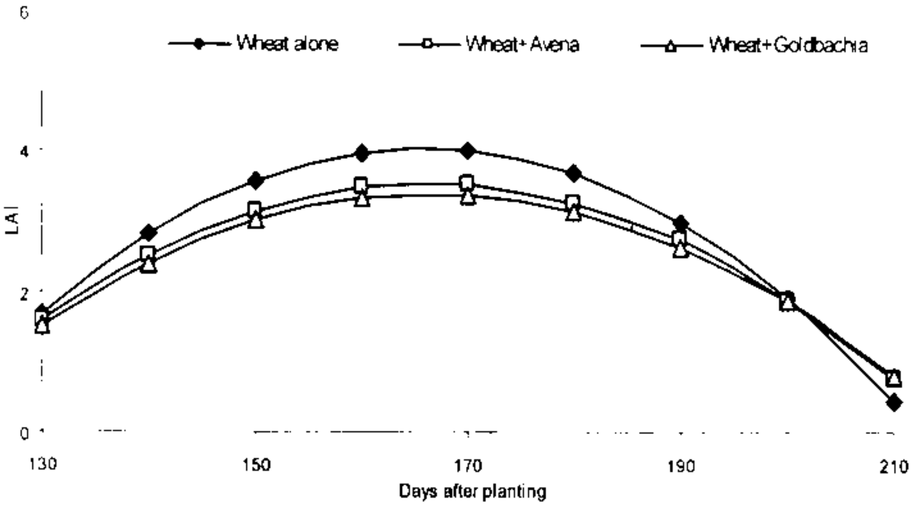

Fig. 3. Wheat leaf area index over the entire growing period under weed free and *A. ludoviciana* and *G. laevigata* infested conditions in 2001-2002.

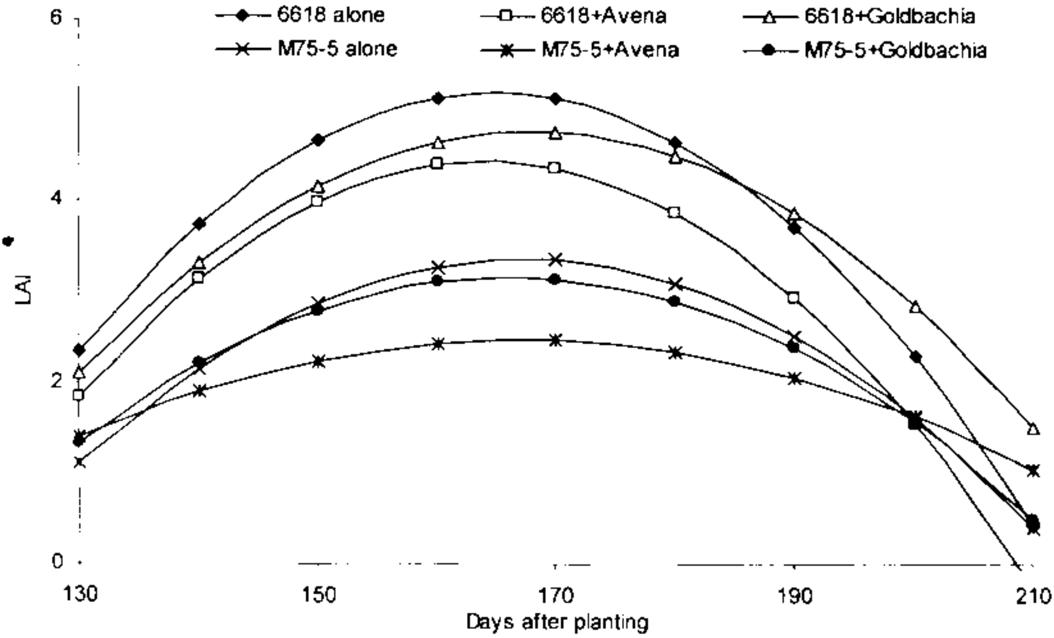

Fig. 4. Leaf area index of 6618 and M-75-5 genotypes over the entire growing period under weed free, *A. ludoviciana*, and *G. laevigata* infested conditions in 2001-2002.

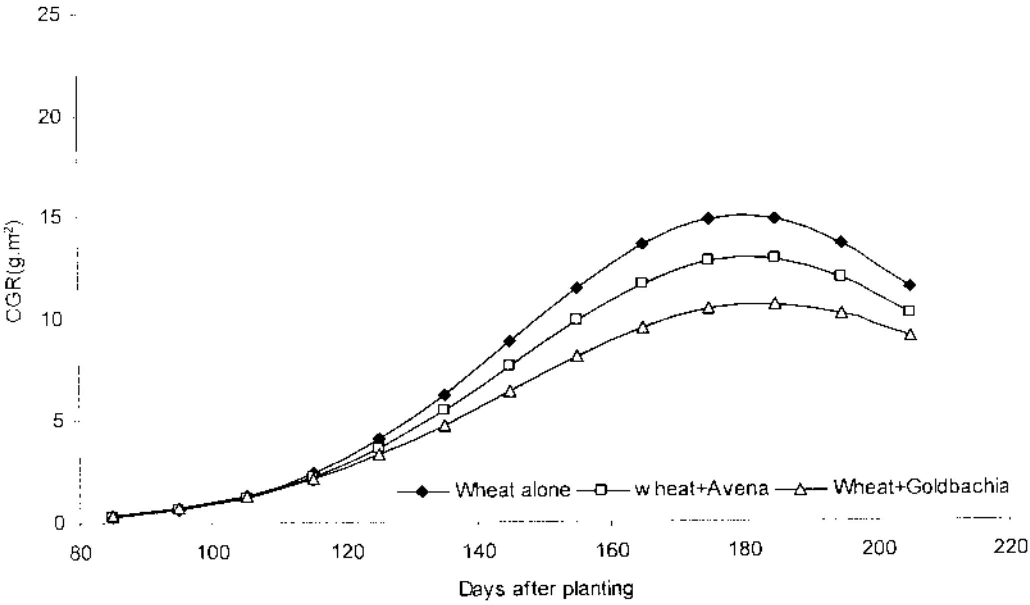

Fig. 7. Wheat crop growth rate over the entire growing period under weed free and *A. ludoviciana*, and *G. laevigata* infested conditions in 2001-2002.

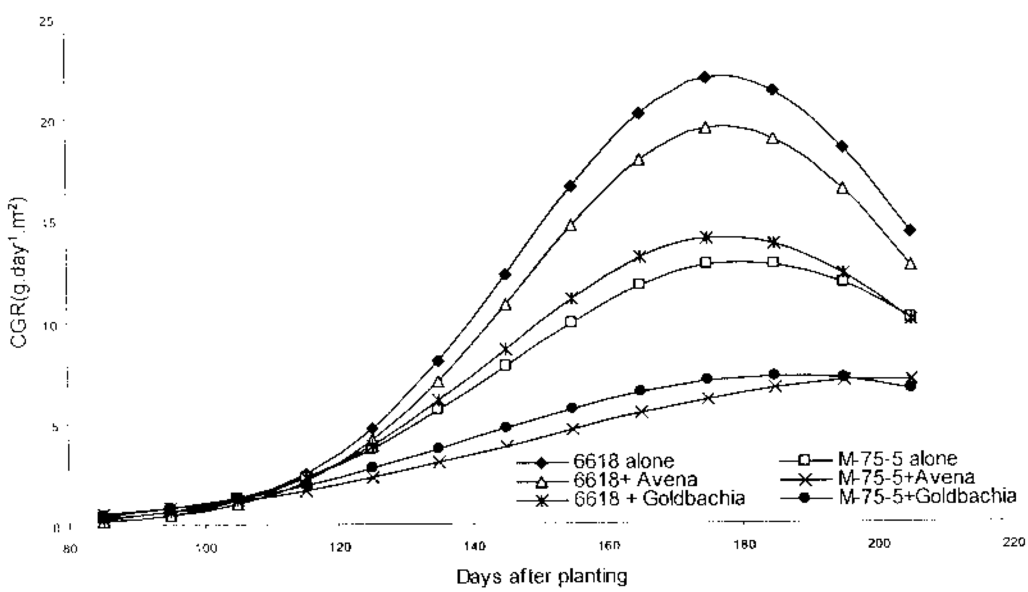

Fig. 8. Crop growth rate of 6618 and M-75-5 genotypes over the entire growing period under weed free and *A. ludoviciana* and *G. laevigata* infested conditions in 2001-2002.

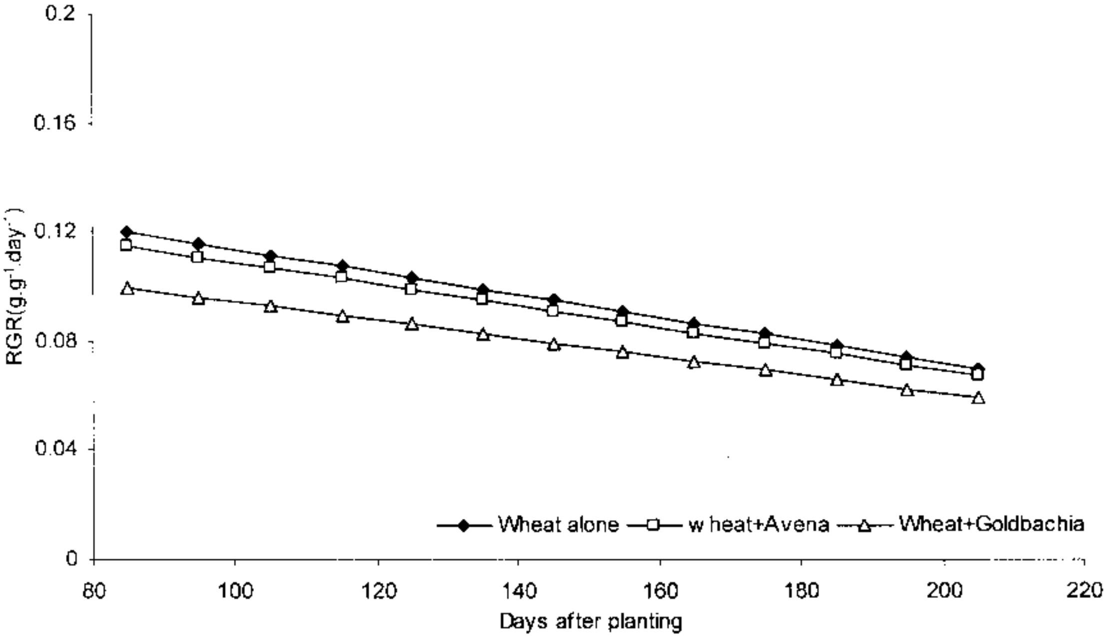

Fig. 9. Wheat relative growth rate over the entire growing period under weed free and *A. ludoviciana* and *G. laevigata* infested conditions in 2001-2002.

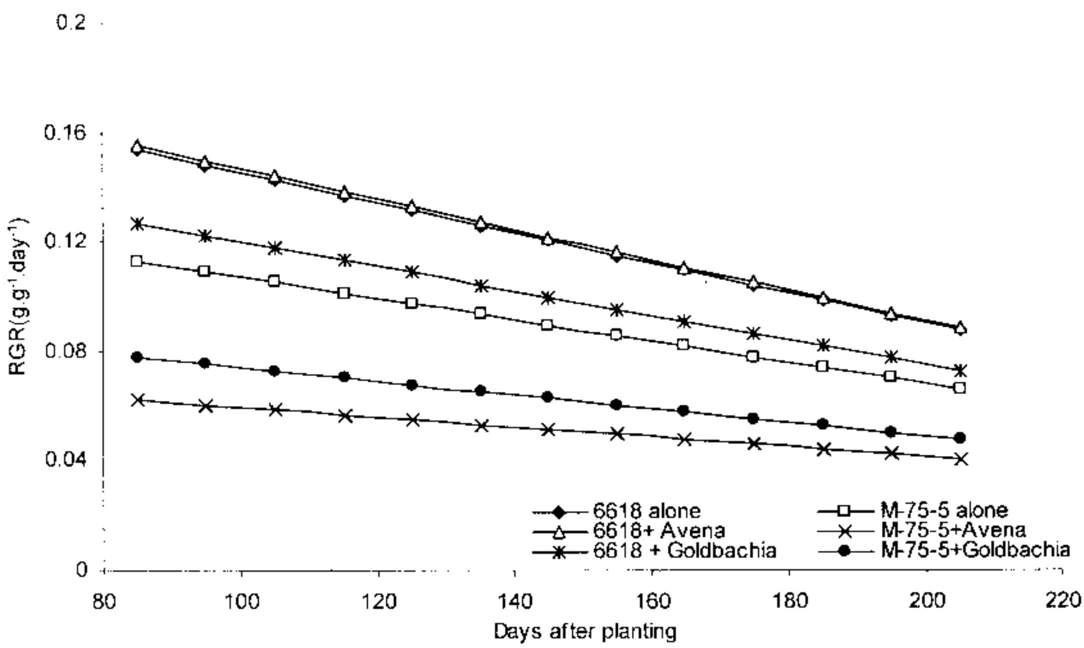

Fig. 10. Relative growth rate of 6618 and M-75-5 genotypes over the entire growing period under weed free and *A. ludoviciana* and *G. laevigata* infested conditions in 2001-2002.

REFERENCES CITED

Blackshaw, R.E. 1994. Differential competitive ability of winter wheat cultivars against downy brome. Agron. J. 86(4): 649–654.

Baghestani, M.A., E. Zand, H. Rahimian Mashhadi and S. Soufizadeh. 2005. Morphological and physiological characteristics which enhance competitiveness of winter wheat (*Triticum aestivum*) against *Goldbachia laevigata*. Iranian J. Weed Sci. 1(2): 111-126.

Baghestani, M.A., E. Zand and S. Soufizadeh. 2006.Iranian winter wheats (*Triticum aestivum* L.) interference with weeds: I. Grain yield and competitive index. Pak. J. Weed Sci. Res. (Accepted for Publication).

Callaway, M.B. 1992. A compendium of crop varietal tolerance to weeds. American J. Altern. Agric. 7(4): 169-180.

Callaway, M.B. and F. Forcella. 1993. Crop tolerance to weeds. *In* M.B. Callaway and C.A. Francis, (eds.). Crop Improvement for Sustainable Agriculture. Lincoln, NE: University of Nebraska Press. pp. 100-131.

Caton, B.P., A.E. Cope and M. Mortimer. 2003. Growth traits of diverse rice cultivars under severe competition: implications for screening for competitiveness. Field Crops Res. 83(2):157-172.

Christensen, S. 1995. Weed suppression ability of spring barley varieties. Weed Res. 35(4): 241-248.

Garrity, D.P., M. Movillon and K. Moody. 1992. Differential weed suppression ability in upland rice cultivars. Agron. J. 84(4):586-591.

Gibson, K.D., J.E. Hill, T.C. Foin, B.P. Caton and A.J. Fischer. 2001. Water-seeded rice cultivars differ in ability to interfere with watergrass. Agron. J. 93(2): 319-325.

Gibson, K.D., T.C. Foin and J.E. Hill. 1999. The relative importance of root and shoot competition between water-seeded and *Echinochloa phyllopogon*. Weed Res. 39(3): 181-190.

Grundy, A.C. and R.J. Froud-Williams. 1993. The use of cultivar, crop seed rate and nitrogen level for the suppression of weeds in winter wheat. Proc. Brighton Crop Protection Conference-Weeds. British Crop Protection Council, Farnham, UK. pp. 997-1001.

Hamblin, J. and J.G. Rowell. 1975. Breeding implications of the relationship between competitive ability and pure culture yield in self-pollinated grain crops. Euphytica 24(1): 221-228.

Jordan, N. 1993. Prospects of weed control through crop interference. Ecol. Appl. 3(1): 84-91.

Kropff, M.J., S.E. Weaver and M.A. Smiths. 1992. Use of ecophysiological models for crop-weed interference: relations amongst weed density, relative time of emergence, relative leaf area, and yield loss. Weed Sci. 40(2):296-301.

Lemerle, D., B. Verbeek, R.D. Cousens and N.E. Coombes. 1996. The potential for selecting wheat varieties strongly competitive against weeds. Weed Res. 36(6): 505-513.

Lemerle, D., G.S. Gill, C.E. Murphy, S.R. Walker, R.D. Cousens, S. Mokhtari, S.J. Peltzer, R. Coleman and D.J. Luckett. 2001. Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Aust. J. Agric. Res. 52(5): 527-548.

Ogg, A.G. (Jr.) and S.S. Seefeldt. 1999. Characterizing traits that enhance the competitiveness of winter wheat (*Triticum aestivum* L.) against jointed goatgrass (*Aegilops cylindrica*). Weed Sci. 47(1): 74-80.

Olesen, J.E., P.K. Hansen, J. Berntsen and S. Christensen. 2004. Simulation of above-ground suppression of competing species and competition tolerance in winter wheat varieties. Field Crops Res. 89(2-3): 263-280.

Pester, T.A., O.C. Burnside and J.H. Orf. 1999. Increasing crop competitiveness to weed through crop breeding. *In* D.D. Buhler (eds). Expanding Context Weed Management. Food Product Press, An Imprint of The Haworth press, Inc. New York, pp. 59-77.

Powles, S.B., C. Preston, I.B. Bryan and A.R. Jutsum. 1997. Herbicide resistance: impact and management. Adv. Agron. 58(1): 57–93.

Radosevich, S.R. and J. Holt. 1984. Weed Ecology: Implications for Vegetation Management. New York: J. Wiley, pp. 93-193.

Rejmanek, M., G.R. Robinson and E. Rejmankova. 1989. Weed-crop competition: experimental designs and models for data analysis. Weed Sci. 37(2): 276-284.

Roush, M.L. and S.R. Radosevich. 1985. Relationships between growth and competitiveness of four annual weeds. J. Appl. Ecol. 22(3): 895-905.

SAS Institute. 1996. SAS/STAT Software: Changes and enhancement through release 6.11. SAS Inst. Inc., Carry, NC, USA.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedure of statistics: A biometrical approach. 2nd ed. McGrow-Hill. New York.

Tanji, A., R.L. Zimdahl and P. Westra. 1997. The competitive ability of wheat (*Triticum aestivum*) compared to rigid ryegrass (*Lolium rigidum*) and cowcockle (*Vaccaria hispanica*). Weed Sci. 45(4): 481-487.

Wang, G., J.D. Ehlers, E.J. Ogbuchiekwe, S. Yang and M.E. McGiffen (Jr.). 2004. Competitiveness of erect, semierect, and prostrate cowpea genotypes with sunflower (*Helianthus annuus*) and purslane (*Portulaca oleracea)*. Weed Sci. 52(5): 815-820.