

## **Evaluation of Some Characteristics Affecting Competitiveness of Eight Iranian Wheat Cultivars with Rocket Weed**

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### **ABSTRACT**

Crops that better tolerate weed competition or preempt resources from weeds may reduce dependence on herbicides and benefit an integrated weed management program. A field trial was conducted to determine the morphophysiological characteristics affecting tolerance and weed suppressive ability of some winter wheat cultivars in competition with Rocket. The experimental treatments consisted of eight wheat cultivars; kept under weed free and weed infested conditions in a randomized complete block design with a factorial arrangement. The results indicated that

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cultivars with greater harvest index (HI) or ability to prevent HI losses in competition with Rocket could balance yield losses and consequently increase their tolerance. Height increase in more competitive cultivars in competition with Rocket, was important in the competitive ability (CA) of these cultivars (as both tolerance and suppressive ability). Those cultivars with higher CA, were taller or had greater rate of stem elongation. Enhancement rate of stem elongation caused an earlier closure of canopy in more competitive cultivars, and consequently through shading on weed, suppressed the Rocket growth. In conclusion, more competitive cultivars possessed a set of characteristics that contribute to their strong competitive ability including high leaf area and vertical leaf area distribution, taller and greater rate of stem elongation, and high early vigor (viability and speed of germination).

**Keywords:** wheat, competitiveness, *Eruca sativa*, morphophysiological characteristics.

## INTRODUCTION

Rocket (*Eruca sativa* Mill.) is a winter annual broadleaf weed that is particularly troublesome in winter wheat fields of Iran (Khodabandeh, 1998). The rocket seed germinates along with wheat, grows rapidly, and establishes a deep and extensive root system, and its growth habit is prostrate. In Iran, farmers use large amount of herbicides to control the broadleaf weeds in cereals fields (Baghestani *et al.*, 2007). The availability of selective herbicides during the last 30 years has enabled farmers to grow high yielding wheat varieties bred and producing optimal yields in weed free conditions. However, the increasing use of herbicides may lead to leaching to ground and surface waters and to adjacent natural areas. Thus, both public and political pressures have increased the emphasis on cultural weed control (e.g. the use of competitive cultivars) methods for prevention of weed problems (Olesen *et al.*, 2004).

Several researchers have examined different morphological and physiological traits of wheat cultivars and their competitiveness with weeds (Blackshaw, 1994; Fischer *et al.*, 2001). In the experiments, characteristics commonly identified to make crops more competitive include rapid germination and root development, higher biomass at tillering, early vigor (e.g. speed of germination), height gain and flag leaf area, vertical leaf area distribution and greater harvest index (Christensen, 1995; Lindquist and Mortensen, 1998; Ogg and Seefeldt, 1999; Lemerle *et al.*, 2001; Weiner *et al.*, 2001; Watson *et al.*, 2002).

In the present experiment, the morphophysiological traits associated with competitive ability of eight wheat cultivars, which are commonly used on wheat agroecosystems in most areas, were studied, in competition with rocket. The morphological traits of more competitive cultivars would enable them to capture resources, or utilize resources more efficiently in comparison to a poorly competitive cultivar. Hence, these traits may be used in breeding programs to release new cultivars with better competitive ability, and consequently reducing herbicide use in wheat production.

## **MATERIALS AND METHODS**

A field trial was conducted to determine the morphophysiological characteristics affecting competitive ability of eight winter wheat cultivars (Table 1) in competition with Rocket weed in Karaj, TE (35° 59' N, 57° 6' E; 1020 masl) during 2003-2004 growing season on a loam clay soil. Two weedy checks (weed free and weed infested) were used with eight wheat cultivars in a factorial experiment in randomized complete block design with four replicates. Each plot consisted of eight rows, of 6m in length and 0.3m row spacing.

In autumn, one plowing operation followed by two disking and land leveling were performed to prepare the seedbed for planting. Ammonium phosphate and urea were applied at rates of 150 and 100 kg ha<sup>-1</sup>, respectively, based on local soil analysis recommendations. Top dress urea was applied at tillering and heading stages at rate of 50 kg/ha each. All weeds except rocket were hand removed during the growing season.

To permit wheat showing its yield potential including competitive ability against weed, each cultivar was planted according to its own optimum density (Table 1). This method is strongly recommended by Tollenaar *et al.* (1994) when comparing different cultivars released in different area so each cultivar was able to show its preferences on another. According to the seed viability, grain weight, and optimum plant density (seeds m<sup>-2</sup>) proposed by Iran Seed and Plant Improvement Institute, KA, each cultivar was then planted at the actual plant density (Table 1). Rocket seeds were planted uniformly and thinned to 80 plants m<sup>-2</sup>.

Table 1. Some attributes of winter wheat cultivars used in this study

Maturity group	Actual plant density (g m <sup>-2</sup> )	Seed 1000-weight (g)	Optimum nitrogen fertilizer (kg ha <sup>-1</sup> )	Optimum plant density (Seed m <sup>-2</sup> )	Release year	Cultivars
early	13	51	-	250	1956	Tabasi
early	13	53	110	250	1958	Roshan
semi-late	10	29	110	325	1976	Karaj2
early	10	27	105	325	1980	Azadi
semi-early	17	37	120	425	1995	Niknejad
semi-early	16	41	130	375	1995	Mahdavi
late	13	32	120	400	2000	Shiraz
late	16	39	120	400	2002	Pishtaz

For estimating leaf area index (LAI) and rate of stem elongation, five 0.18m<sup>2</sup> destructive samples (after omitting border effects) were taken from each plot at two week intervals starting 20 March. Leaf area was measured with a leaf area meter (LI-3100A, LiCor Inc., Lincoln, Nebraska, USA). Plant height was measured as distance between root crown and the first fully expanded leaf. Quadratic polynomial functions were fit to leaf area index and plant height data to describe the relationship between each trait and time. Rate of stem elongation was then calculated as the slope of quadratic increase in plant height. All graphs were plotted on a thermal time scale. The base temperature used for estimation of the growing days was 4°C. At canopy closure (approximately Zadoks 61-68), a destructive sample was taken for measuring vertical leaf area distribution. Plants which were harvested from a 0.18m<sup>2</sup> plot were separated into 20cm layers leaf area of each layer was measured. At harvest, four outer rows of each plot and 50cm from each end of the plots were left as borders and the middle 1m of the 4 center rows were harvested and separated into weed and wheat stands, Wheat grain yield, plant height, and weed biomass were measured. Harvest index (HI) was calculated as the proportion of grain yield to biological yield.

Speed of germination on wheat cultivars were calculated from the Maguire equation as follow (Maguire, 1962):

$$\text{Speed of germination} = \left( \frac{X_1}{Y_1} \right) + \left( \frac{X_2 - X_1}{Y_2} \right) + \dots + \left( \frac{X_n - (X_{n-1})}{Y_n} \right) \quad (1)$$

where  $X_n$  is percentage of germinated seeds at count  $n$ , and  $Y_n$  is days from planting to count  $n$ . The frequency of the germination counted to estimate the speed of germination was every subsequent day.

Lodging percent for all cultivars in competition with rocket was recorded using a scoring system from 1 to 9. Score 1, when there was no sign of lodging, 5 when half of plot was lodged and 9 when the whole plot was fallen. Lodging estimation was performed by Zadoks 90. Since the variances within the groups were equal here, this trait was not analyzed via ANOVA. Therefore the results are presented without statistical analysis.

The assumptions of the variance analysis were tested by insuring whether residuals were homogenous (using Bartlett test), with normal distribution about a mean of zero. In addition, data were tested for normality using the Anderson-Darling statistic as generated by the PROC UNIVARIATE procedure by SAS (Ver. 8.02, SAS Institute Inc., Cary, NC). The assumptions of variance were adequately met, and there were no need for data transformation. Means were separated using Duncan multiple range test set at 0.05. In conditions where weed and wheat cultivar interaction existed as a trait, data were presented separately by the weed condition (weedy and weed free).

## **RESULTS AND DISCUSSION**

### **Grain Yield, Harvest Index and Competitive Ability**

Generally, an ideal cultivar in crop-weed competition will have high yield potential in both weedy and weed-free situations, will tolerate weeds and significantly suppress their growth (through reducing weed biomass). In the previous work (Deihimfard *et al.*, 2006), the authors concluded that Tabasi and Karaj2 were less and more competitive cultivars, respectively (according to the two indices calculated for the cultivars, namely CI and AWC). In fact, based on different earlier studies, it was concluded that Tabasi is not a good competitor for Rocket; however, Karaj2 has strong competitiveness against rocket. Although Pishtaz and Shiraz cultivars have high yield under weed-free conditions, due to their lower competitive indices comparing to

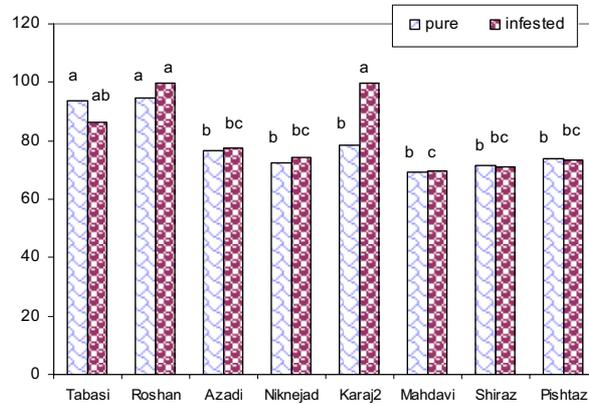
Karaj2, they did not introduce as more competitive cultivars (Deihimfard *et al.*, 2006). Variation in the competitive ability (CA) of wheat cultivars has been reported (Blackshaw 1994; Lemerle *et al.*, 2001). Tepe *et al.* (2005) investigated the effects of weeds on different lentil (*Lens culinaris* L.) cultivars and concluded that there were differences among CA of cultivars.

HI in both less and more competitive cultivars was similar (Table 3). The highest HI belonged to tolerant cultivar of Roshan which its HI in weedy conditions was greater than that in weed-free. Therefore, it can be concluded that those cultivars, which can increase their HI or prevent losses in competition with Rocket, could balance their yield losses and increase tolerance. Results of correlation analysis is an indicator of high relatively relationship between HI and competitive ability (data not shown). Lindquist and Mortensen (1998) also, stated that in crop tolerance, dry matter partitioning into different organs is more important than total cumulative dry matter. Altieri and Liebman (1988) also reported that enhancing HI in competition with weeds is the main reason of tolerance to weeds.

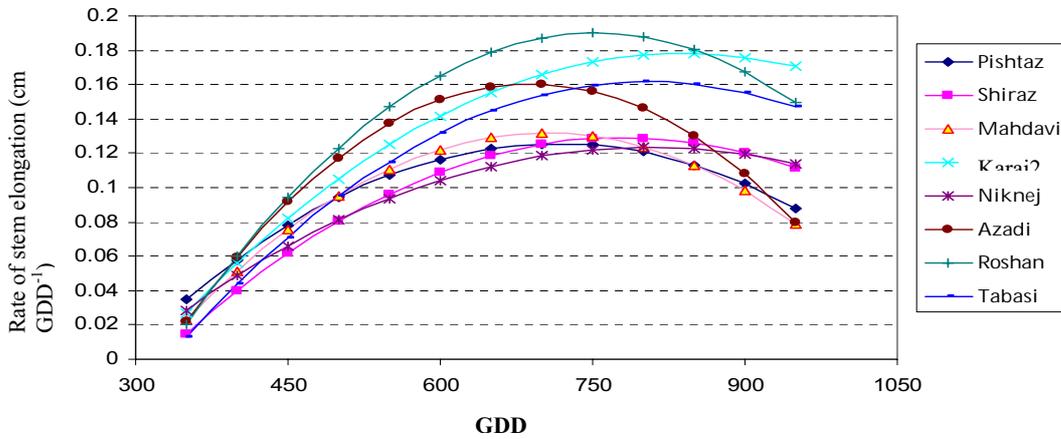
#### **Final Height and Rate of Stem Elongation**

The results indicated that the effect of Rocket on wheat height was the same among cultivars. In addition, there were significant differences among cultivars ( $P < 0.0001$ ), in this respect (Figure 1). In other words, the interaction between weed and wheat cultivar was not significant in case of plant height, but data are presented separately based on weed conditions to highlight the importance of this trait making a cultivar more competitive cultivar against weeds. For example, tolerant cultivars (Karaj2 & Roshan) had the highest height, and the lowest height belonged to Mahdavi (as a less competitive cultivar). Height of Karaj2 and Roshan under weed competition increased from 78cm and 94cm in pure plots to 99cm in infested plots, respectively (Figure 1).

Increase in height was one of the important aspects of competitive ability (CA) of the mentioned cultivars. Berkowitz (1988) stated that weed-crop competition in earlier growth stages could increase the height of crop cultivars. This is probably due to change in the light quality within canopy (reduction in R/FR ratio) and subsequent cell size increase, which is related to mechanisms of shade avoiding (Rohrig & Stunzel, 2001). Consequently, growth and biomass production of Rocket was reduced due to shading and hence yield losses of Karaj2 and Roshan was prevented. Although Tabasi cultivar (as a less competitive) was taller, but its less competitive ability was mostly related to a large reduction in HI and leaf area in competition with Rocket (Table 3 & Figure 4). As a result, height could not affect CA solely, but in companion with other traits such as LAI; many studies suggest that the importance of varietal height to crop CA may also be linked to other factors such as early crop vigour, leaf characteristics, or shading ability (Verschwele, 1994; Huel & Hucl, 1996; Lemerle *et al.*, 1996; Ogg & Seefeldt, 1999; Seavers & Wright, 1999). Traore *et al.* (2003) also, stated that development of tall sorghum hybrid with more LAI would be useful for integrated weed management.



**Figure 1.** Mean comparisons of height among wheat cultivars in weedy and weed-free conditions



**Figure 2.** Rate of stem elongation of wheat cultivars through growing season in

Table 2. Results of ANOVA for some wheat traits.

Source of variation	df	MS			
		Grain yield	Harvest index	Height	Flag leaf area
block	3	306434.06	0.0017	94.64	5377.83**
cultivar	7	2683454.8**	0.0077	816.62**	1986.09
weed	1	63851416.06**	0.0344**	99.90	35.43
cultivar × weed	7	4421493.7**	0.0076	139.42	613.78
error	49	332512.4	0.004328	90.3002	930.817
C.V. %	-	14.30	19.40	11.83	26.49

\*\* Significant at the 0.01 probability level.

Table 3. Mean comparisons of grain yield and harvest index in weedy and weed free treatments

cultivars	Weedy		Weed-free	
	Grain yield (kg ha <sup>-1</sup> )	Harvest index	Grain yield (kg ha <sup>-1</sup> )	Harvest index
Tabasi	2012d	0.25a	4767b	0.31c
Roshan	3152b	0.36a	3241c	0.31c
Karaj2	3288a	0.27a	3865c	0.31c
Azadi	3124b	0.29a	5841ab	0.44a
Niknejad	2330cd	0.27a	5928ab	0.36bc
Mahdavi	2758bc	0.36a	6294a	0.40ab
Shiraz	3155b	0.31a	5446ab	0.38abc
Pishtaz	3890a	0.33a	5786ab	0.36bc

Means within a column followed by the same letters are not significantly different according to Duncan's multiple range test at  $P < 0.05$ .

Figure 2 indicates rate of stem elongation of wheat cultivars in competition with Rocket. These cultivars which were taller (e.g. Roshan & Karaj2), also had higher rate of stem elongation during growth stages. Results of correlation analysis also verify strong relationship between final height and rate of stem elongation (data not shown). Therefore, the cultivars, which had higher CA (as tolerance), were either taller or had higher rate of stem elongation. Greater rate of stem elongation resulted in an earlier closure of the more competitive cultivars canopy and therefore, led to reduction in growth of Rocket, due to shading. Ogg and Seefeldt (1999) also, in their study of traits affecting CA of wheat cultivars against *Aegilops cylindrica* mentioned that height gain is one of the most important traits that affect CA enhancement in infested conditions. Therefore, it is recommended that we use rate of stem elongation in the breeding programs for enhancing CA.

#### **Seed Viability and Speed of Germination**

Seed viability (seed's ability to germinate and grow) and speed of germination are two components of early vigor. Early vigor is the expression of relatively high growth rate and high rate of emergence. An ability to achieve an early large size early will be expected to confer later crop CA (Bastiaans *et al.*, 1997; Seavers & Wright, 1999). The results of seeds viability (Table 4) showed that there were no differences among cultivars in the first count (four days after planting) and final count (eight days after planting). It is observed that all of the wheat cultivars had high seed viability and so this trait had no effect on CA of cultivars in competition with Rocket. Nevertheless, speed of germination differed significantly among cultivars (Table 4). Tolerant cultivars (e.g. Roshan and Karaj2) had greater speed of germination than less competitive cultivars (e.g. Niknejad & Mahdavi). Tabasi as a less competitive cultivar had high speed of germination. Therefore, low CA of Tabasi is mostly related to its

other growth traits such as lower leaf area index and rate of stem elongation, biomass at tillering and etc. Early high vigor and early rapid growth of the cultivars with high speed of germination resulted in a fast coverage of soil and therefore reduction in light penetration into the canopy and consequent increase in CA of these cultivars against weeds (Rebetzke & Richards, 1999). Also, Pavlichenco and Harrington (1934, 1935) pointed to photosynthesis area expansion and uniform and fast germination as the most important traits affect CA,

#### **Flag Leaf Area and Lodging Percent**

The results indicated that flag leaf area was not significantly different between weedy and weed-free conditions (Table 2). However, differences were observed among cultivars (Table 4). The more competitive cultivars (Rosjan & Karaj2) had highest flag leaf area, and the lowest belonged to Pishtaz and Niknejad. With regard to the rate of flag leaf in canopy photosynthesis and its role of transportation of 50% of the total carbohydrate into grain, it could be concluded that probably more competitive cultivars in competition with Rocket due to greater flag leaf area compensated for the lost carbohydrate in competition and prevented yield losses due to the competition. Watson *et al.* (2002) also stated that the size of flag leaf was positively correlated to CA of barley cultivars.

Lodging index was not different between weedy and weed free conditions. Therefore, Rocket did not have any effect on lodging of cultivars and lodging was mostly related to other characteristics. Tabasi, Roshan and Karaj2, which were taller among other cultivars, also had the highest lodging index. So, although possessing higher height can result in more CA (tolerance and suppression), but care should be taken that very tall plant as a trait affecting CA at breeding programs, can increase lodging index and consequently reduce grain yield in competition (Mohler, 2001).

Table 4. Results of seeds viability, speed of germination, flag leaf area, and lodging index

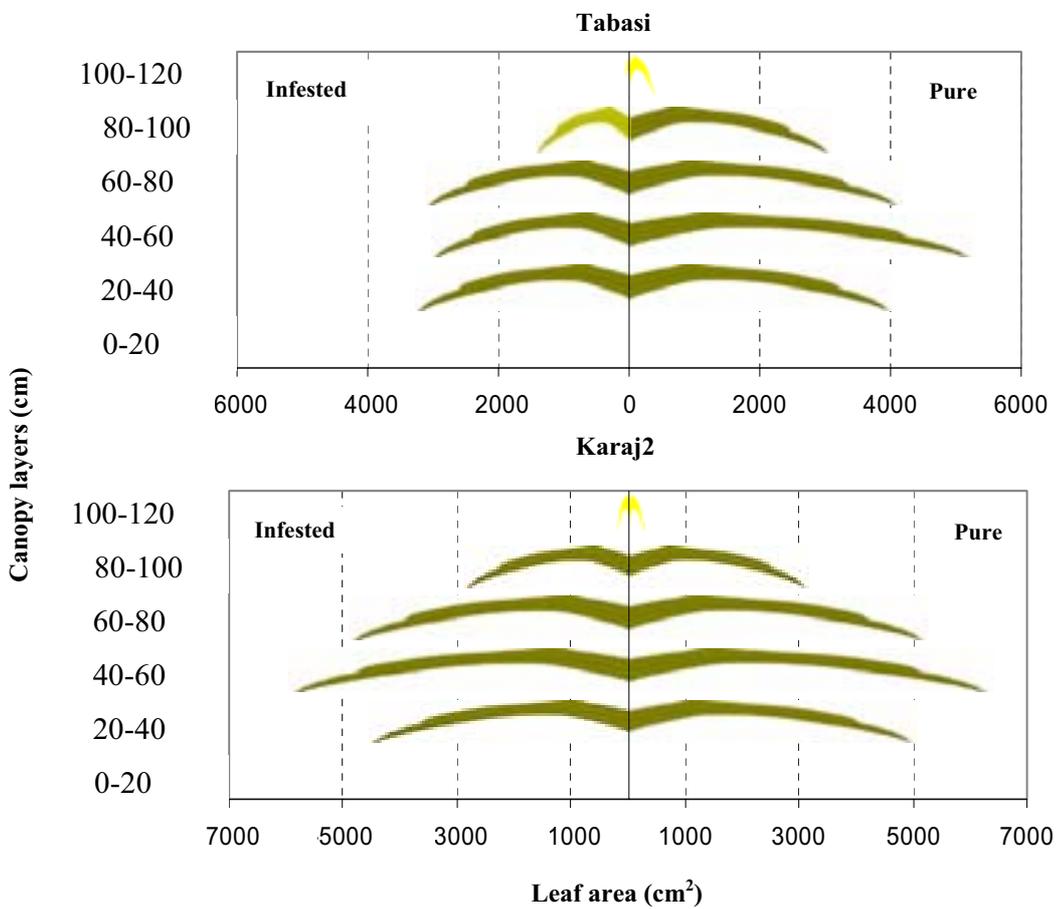
Cultivars	Seed viability (%)		Speed of germination (relative germination day <sup>-1</sup> )	Flag leaf area (cm <sup>2</sup> )	Lodging index (%)
	First count	Final count			
Tabasi	98	98	0.85a	118a	5.55
Roshan	99	99	0.86a	134.88a	18.05
Karaj2	93	93	0.67b	125.43a	16.66
Azadi	91	91	0.62bc	122.83a	0
Niknejad	92.5	92.5	0.42d	103.73ab	0
Mahdavi	95	95.5	0.63bc	106.42ab	0
Shiraz	97.5	97.5	0.63bc	127.10a	0
Pishtaz	97	97	0.59c	77.39b	2.77

Means within a column followed by the same letters are not significantly different according to Duncan's multiple range test at  $P < 0.05$ .

### **Vertical Leaf Area Distribution**

Since vertical leaf area distribution is an indicator of light distribution and penetration into crop canopy, cultivars which can concentrate greater leaf area at top of the canopy, can result in more CA. Figure 3 indicates vertical leaf area distribution of less and more competitive cultivars in weedy and weed-free conditions. In all cultivars, leaf area of each layer was reduced in weedy plots compared to pure plots. In Tabasi, there were no differences among layers in competition with Rocket and leaf area distribution was almost similar among layers. In contrast, leaf area distribution in more competitive cultivar (Karaj2) was similar in weedy and weed-free plots. Also, in upper layers (80-100 cm) leaf area was greater in more competitive cultivar. Giving attention to Rocket height (maximum 70 cm), greater leaf area in the upper layers in

more competitive cultivars in comparison with that of less competitive caused more shading on Rocket and a consequent prevention of light interception and Rocket growth. Cavero *et al.* (1999) and, Lindquist and Mortensen (1998) reported that vertical leaf area distribution is the most effective trait on competitiveness, especially when crop and weeds have different heights.



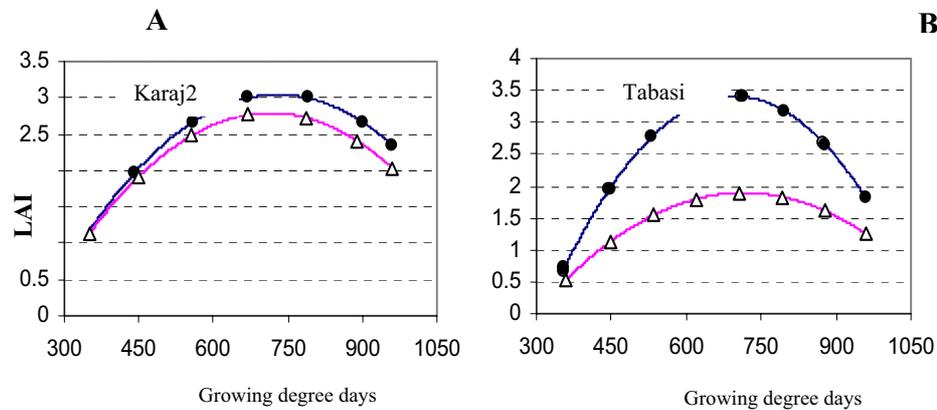
**Figure -3.** –Vertical leaf area distribution of less (Tabasi) and more (Karaj2) competitive cultivars in weedy and weed-free conditions

### **Phenological Stages of Cultivars**

Comparison of phenological stages in Zadoks scale (Zadoks *et al.*, 1974) of wheat cultivars in weedy conditions showed that there are differences in growth and development stages of cultivars. Mahdavi and Niknejad (as less competitive cultivars) had shorter life cycle than other cultivars (nearly 2 or 3 weeks). Nevertheless, with regard to growth cycle of Rocket that was shorter than that of wheat cultivars at grain filling stage of Rocket, wheat field was green except for Mahdavi and Niknejad It seems that wheat phenology could not be probably considered a important trait affecting CA. On the contrary, Fischer *et al.* (2001) reported early maturity of rice is a desired characteristic for the rice-*Brachiaria* spp. competition.

### **Leaf Area Index (LAI)**

Rocket reduced leaf area of all cultivars and this reduction was not similar among cultivars during the growing season. The highest reduction belonged to Tabasi cultivar (Figure 4A). LAI of Karaj2 in weedy condition was nearly similar to that of pure plot during the growing season (Figure 4B). That cultivar, which can refrain from leaf area losses in competition (i.e. Karaj2), will be able to have greater photosynthesis and consequently more dry matter production. Also, by preventing leaf area losses and shading on weed, the consequent reduction in weed biomass would be resulted (biomass of Rocket in competition with Karaj2 was mostly reduced in comparison with less competitive cultivars, data not shown). Fischer *et al.* (2001) reported that leaf area is an important trait affecting CA of cultivars. Traore *et al.* (2003) also, stated that development of tall sorghum hybrid with high LAI would benefit their CA.



**Figure 4.** Leaf area index of a less and more competitive cultivars in weedy ( $\Delta$ ) and weed-free ( $\bullet$ ) conditions

### Conclusions

Highly competitive varieties often have a set of characteristics that contribute to CA. In many experiments, the greater competitiveness of a more cultivar could be attributed to rapid emergence and canopy closure, extensive branching and dense foliage, and maintenance of a closed canopy for a greater portion of season. The results of the present study revealed that several characteristic are related to high CA of wheat cultivars including high leaf area, vertical leaf area distribution, higher height, greater rate of stem elongation, and early vigor (viability and speed of germination). Also, it was concluded that breeding in modern varieties (e.g. Pishtaz, Mahdavi & Shiraz) has reduced plant height and tillering ability and increased harvest index; thus, it is difficult to separate out the effects of these traits when comparing old (Roshan, Karaj2 & Niknejad) with modern varieties. The use of higher height due to its usefulness in breeding for crop CA, should be noticed because taller plants are often associated with lower yields due to reduction in harvest index and increased susceptibility to lodging. However, if two current varieties have similar yield potential

in infested conditions but differ in height, the taller varieties could be recommended to farmers for their weedy fields (e.g. Karaj2 in comparison with Shiraz).

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#### **REFERENCES**

- Allen, J. R. 1983. Leaf number and maturity in hybrid corn. *Agronomy Journal* **65**: 233-235.
- Altieri, M. A. 1999. The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystem and Environment* **74**: 19-31.
- Banik, P. and Bagchi, D. K. 1994. Evaluation of rice (*Oryza sativa*) and legume intercropping in upland situation of Bihar plateau. *Indian Journal of Agricultural Sciences* **64**: 364-368.
- Banik, P. Midya, A., Sarkar, B. K. and Ghose, S. S. 2006. Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. *European Journal of Agronomy* **24**: 325-332.
- Brummer, E. C. 1998. Diversity, stability, and sustainable American agriculture. *Agronomy Journal* **90**: 1-2.
- Baumann, D. T., Kropff, M. J. and Bastiaans, L. 2000. Intercropping leek to suppress weeds. *Weed Research* **40(4)**: 359-374.
- Carruthers, K. Prithviraj, B., Cloutier, Q. Fe. D., Martin, R.C. and Smith, D. L. 2000. Intercropping corn with soybean, lupin and forages: yield component responses. *European Journal of Agronomy* **12**: 103-115.
- Carruthers, K., Cloutier, F.E. and Smith, D. L. 1998. Intercropping corn with soybean, lupin and forages: Weed control by intercrops combined with interrow cultivation. *European Journal of Agronomy*. **8**: 225-238.
- Evans, L. T. 1998. Feeding the Ten Billion, plants and population growth. Cambridge University Press, Cambridge.

- Exner, D. N. and Cruse, R.M. 1993. Interseeded forage legume potential as winter ground cover, nitrogen source, and competition. *Journal of Production of Agriculture*. **6**: 226–231.
- Fukai, S. and Trenbath, B. R. 1993. Processes determining intercrop productivity and yields of component crops. *Field Crops Research* **34**: 247–271.
- Giller, K.E. Cadisch, G. 1995. Future benefits from biological nitrogen fixation: An ecological approach to agriculture. *Plant Soil* **174**: 225–277.
- Hauggaard-Nielsen, H. Andersen, M. K., Jørnsgaard, B. and Jensen, E. S. 2006. Density and relative frequency effects on competitive interactions and resource use in pea–barley intercrops. *Field Crops Research* **95**: 256–267.
- Hauggaard-Nielsen, H., Ambus, P. and Jense, E. S. 2001. Interspecific competition, N use and interference withweeds in pea-barley intercropping. *Field Crops Research*. **70**: 101–109.
- Hayder, G., Mumtaz, S. S., Khan, A. and Khan, S. 2003. Maize and soybean intercropping under various levels of soybean seed rates. *Asian Journal of Plant Science*. 2(3): 339–341.
- Holm, L. Doll, J. Holm, E. Pancho, J. and Herberger J. 1996. World weed, natural histories and distribution. John Wiley & Sons, Inc.
- Hume, D. F., Shanmugasundaram, S. and Beversdorf, W. I. D. 1985. Soyabean (*Glycine max* (L.) Merrill ). In: Summerfield R.J., Roberts, E.H. (Eds.), *Grain Legume Crops*. William Collins, London, pp. 391–432.
- Jeyabal, A. and Kuppaswamy, G. 2001. Recycling of organic wastes for the production of vermicompost and its response in rice–legume cropping system and soil fertility. *European Journal of Agronomy* **15**: 153–170.
- Li, L., Sun, J., Zhang, F., Li, X., Yang, S. and Rengel, Z. (2001). Wheat/maize or wheat/soybean strip intercropping, I. Yield advantage and interspecific interactions on nutrients. *Field Crops Research* **71**: 123–137.
- Liebman, M. and Dyck, E. 1993. Crop rotation and intercropping strategies for weed management. *Ecology Applied* 3(1):92–122.
- Liebman, M. and Davis, A. S. 2000. Integration of soil, crop and weed management in low-input farming systems. *Weed Research* **40**: 27– 47.

- Maingi, M. J., Shisanya, A.C., Gitonga, M. N. and Hornetz, B. 2001. Nitrogen fixation by common bean (*Phaseolus vulgaris* L.) in pure and mixed stands in semi arid South east Kenya. *European Journal of Agronomy* **14**: 1–12.
- Marchiol, L., Miceli, F., Pinosa, M. and Zerbi, G. 1992. Intercropping of soybean and maize for silage in northern Italy. Effect of nitrogen level and plant density on growth, yield, and protein content. *European Journal of Agronomy* **1**: 207–211.
- Martin, R. C., Voldeng, H. C. and Smith, D. L. 1990. Intercropping corn and soybean in a cool temperate region: yield, protein and economic benefits. *Field Crops Research* **23**:295–310.
- Morris, R. A. and Garrity, D. P. (1993). Resource capture and utilization in intercropping: non-nitrogen nutrients. *Field Crops Research* **34**: 303-317.
- Poggio, S. L. 2005. Structure of weed communities occurring in monoculture and intercropping of field pea and barley. *Agriculture, Ecosystem and Environment*. **109**:48–58.
- Regnier, E. E. and Stoller, E. W. 1989. The Effects of Soybean (*Glycine max*) Interference on the Canopy Architecture of Common Cocklebur (*Xanthium strumarium*), Jimsonweed (*Datura stramonium*), and Velvetleaf (*Abutilon theophrasti*). *Weed Science* **37**: 187-195.
- SAS Institute, (2002). SAS User's Guide: Statistics. Version 8, SAS Institute, Cary, North Carolina, USA.
- Singh, N. B., Singh, P.P. and Nair, K. P. P. 1986. Effect of legume intercropping on enrichment of soil nitrogen, bacterial activity and productivity of associated maize crops. *Experimental Agriculture* **22**: 339–344.
- Tetio-Kagho, F. and Gardner, F. P. 1988. Response of maize to plant population. II: Reproductive development on yield and yield adjustment. *Agronomy Journal* **80**: 935-945.
- Thiyagarajan, C. R. 1994. Studies on the quality of seeds of component crops in maize based intercropping. *Madras Agricultural Journal* **81**: 46-47.
- Van Kessel, C. and Hartley, H. 2000. Agricultural management of grain legumes: Has it led to an increase in nitrogen fixation. *Field Crops Research* **65**: 165-181.
- Vandermeer, J. 1989. *The Ecology of intercropping*. Cambridge University Press, Cambridge, UK.

- Vandermeer, J. 1995. The ecological basis of alternative agriculture. *Annual Review Ecological Systems* **26**: 201–224.
- Vandermeer, J., Van Noordwijk, M., Anderson, J., Ong, C. and Perfecto, I. 1998. Global change and multi-species agroecosystems: Concepts and issues. *Agriculture Ecosystem and Environment* **67**: 1–22.
- Weil, R. R. and Mc Fadden, M. E. 1991. Fertility and weed stress effects on performance of maize/soybean intercrop. *Agronomy Journal*. **83**:717-721.
- Zimdahl, R. L. 1993. *Fundamentals of weed Science*. Academic Press, New York.