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Water Use Efficiency Variation and Its Components in Wheat Cultivars

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Authors' contributions

This work was carried out by the two authors. Author AE designed the study performed the statistical analysis and first draft of the manuscript. Author FH assisted in the design wrote the protocol, description of wheat varieties and also in the literature searches. Both authors read and approved the final manuscript.

Research Article

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ABSTRACT

Genetic variations of water use efficiency (WUE) in wheat cultivar were studied in different models. These models in addition accumulating WUE; evaluate the contribution of its components. In this study, seven bread wheat cultivars were sown at four separate randomized complete block design with four replications at different moisture regimes in two growing seasons. Combined analysis of variance showed significant differences for total dry matter, WUE, relative water loss (transpiration efficiency), and initial water of flag leaves (uptake efficiency). Sardary, Sabalan and Alamut cultivars had the lowest WUE and total dry matter, but Zarrin and Shahriar were the highest values. Sardary with low uptake efficiency and Zarrin with high grain yield had the minimum and maximum transpiration efficiency. The WUE and evapotranspiration efficiency had a positive significant correlation with total dry matter and grain yield respectively. Results of path analysis showed that WUE (0.6) and total dry matter (0.31) had the highest direct effect on grain yield. Contribution of evapotranspiration efficiency (0.82) on WUE was higher than harvest index (0.30).

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Keywords: Water use efficiency; evapotranspiration efficiency; wheat; harvest index.

1. INTRODUCTION

About 80% of the world's allocated water resource is currently consumed by irrigated agriculture. This level of consumption by agriculture is not sustainable into the future. It is necessary to produce the maximum yield per unit area by using available water because irrigation water is rapidly diminishing around the world. At present and more so in the future, Irrigation management will shift from emphasizing production per unit area towards maximizing the production per unit of water consumed. It is essential to develop the most suitable irrigation schedule to produce the maximum plant yield. Such schedule should be developed for different ecological regions, as plant water consumption during the vegetation period depends mostly on plant growth, soil and climatic conditions [1]. In additional, water deficit is one of the most important environmental factors constraining crop photosynthesis and productivity in arid and semi-arid areas [2]. In semiarid areas, production is mainly limited on rainfall time and distribution of precipitation and low nutrient availability. The WUE is the ratio of net CO_2 assimilation to water used [3]. CO_2 assimilation may be in terms of net CO_2 exchange, dry matter growth, and economic yield, while water used may be determined by mass or molar unit [3]. According to [4] WUE could be defined as: short-term gas exchange on a photosynthesis basis (WUE_{photo}), a biomass basis (WUE_{bio}), or a yield basis (WUE_{grain}). Wheat WUE has been reported to be decreasing with the increase in irrigation times and amount of irrigation water per growing season [4]. 'Water-use efficiency' as a breeding target could be defined in many ways, depending on the scale of measurement and the units of exchange being considered [5]. For physiologists, the basic unit of production could be moles of carbon gained in photosynthesis and the physiological definition might equate, at its most basic level, to the instantaneous water exchange rate for consumed water in transpiration. For farmers and agronomists, the unit of production is much more likely to be the yield of harvested product that achieved from the water consumed for crop through precipitation and/or irrigation. Farmer's definition is one of agronomic water-use efficiency [5]. The relative importance of WU and WUE is dependent on the level of water availability in the soil [6].Trait like water use efficiency in both breeding activity and physiological studies is particularly useful when a large number of genotypes are assessed. This were a crucial point since a thorough characterization required for understanding the mechanisms governing WUE and their role in maintaining crop yield in contrasting environments can usually be done on few genotypes only, thus preventing the identification of the multiple strategies to withstand water stress adopted by different genotypes even within the same species.

2. MATERIAL AND METHODS

Plant materials were sown in four randomized complete block designs, with four replications in loam silty soil in the close location. Five wheat varieties were used in this study (sahand, sardari, sabalan, shahriar, zarrin, martan and alamot). The experiment was carried out in Western Azerbaijan agricultural research center at Miandoab station in growing season 2010-11. The experimental field station was located in latitude 36°58´, longitude 46°6´ and altitude 1371m, by a typical silty loam texture. Each randomized complete block includes irrigation level, which Irrigation water was measured by two-inch volumetric meter. Beta coefficients (formula number 1) in Table 1 were used to determine the timing of irrigation and to supply the soil moisture.

(1) - θ = Fc- (MAD *100/D * Gs * β)

In these formula θ= the irrigation water, Fc= field capacity, MAD= Soil moisture deficit, D= Depth of root development, Gs= Soil bulk density and β= irrigation.

The experimental site was fallow against hard pan layers plowed by sub soiler at depths of 50 cm and then plowed was destroyed by the disks. Based on soil analysis test, 30 kg/ha urea fertilizer per year distribute in 3 growth stage (sowing date, stem elongation and heading stage) a 100 kg/ha phosphorus and 90 kg per ha/ha Potassium were distribute in the field each year. The Furrow bank width and length were 60 cm and 200 cm respectively. Each plot planted in three rows on top of the Furrow bank and watered immediately. Total dry matter, grain yield, harvest index, water use efficiency, evapotranspiration efficiency, primary water and flag leaves water losses rate were measured as R.W.L. Four leaf fresh weights per plot were recorded base on [7] procedure (W_0). Then harvested fresh leaves were incubated at 25 °c and 50% relative humidity for 6 h and dry weight were measured every two hours (respectively, W_2, W_4 and W_6). After measured the dry samples (W_d) water loss rate of leaf (R.W.L) (gr $gr^{-1}h^{-1}$) was calculated according to the following formula (formula number 2).

(2) - R.W.L= $[(W_0-W_2) + (W_2-W_4) + (W_4-W_6)] / [3\times W_d (T^2-T^1)]$

In these formula T^2 - T^1= Interval between two weight measurement based on the time.

At the other hand WUE (grain yield / total water used) = evapotranspiration efficiency (total dry matter /the total water used)×harvest index (grain yield / total dry matter).If we use additive log from the model as in the **(**Y= X1+X2) formula, it can participate and calculate each component of the sum of squares of water use efficiency according to [8] and it was the ways that we can be investigated the way and effective factor of WUE increase in plants. Two seasons data analysis were done with Mstat-C software and Path analysis based on the method described by Lu [9] were done by SPSS software.

Table 1. Features of four irrigation regimes in two year

year	Irrigation coefficient (β)	Volume of consumed water (Li)	Irrigation frequency	Irrigation period (day)
1	1	5140	7	10
	0.85	4890	6	12
	0.7	4750	5	14
	0.55	4360	4	17
2	1	4140	7	8.8
	0.85	3570	6	10.4
	0.7	2920	5	13
	0.55	2350	4	16.3

3. RESULTS AND DISCUSSION

The results of two year Combined analysis for agronomic traits in two-year and four irrigation regimes on seven wheat cultivars showed that there were significant differences between traits such as harvest index and flag leaf water content. Furthermore, result was showed that traits except rate of water loss and flag leaf primary water loss in four levels of irrigation regimes were significant ($p<0.01$) (Table 2). At the other hand, for most traits the interaction between year and irrigation regimes level was significant. Also result was showed that Between traits for total dry matter, water use efficiency, water lose rate and flag leaf primarily water content, was significant and it were belong to variation among cultivars in terms of observed traits. Significant water use efficiency traits, allowing the development of more efficient water use in wheat genotypes. These were due to genotypic differences in photosynthetic capacity and greater mobility of accumulated carbon in the stems before pollination during the grain filling period. Genetic differences in initial water content and flag leaf water loss rate is probably due to differences in root systems (distribution and its density), Genetic differences in initial water content and flag leaf water loss rate is probably due to differences in root systems (distribution and its density), the efficiency of water uptake by the roots of plants, primary growth and transpiration efficiency (stomatic system), respectively. Interaction, of moisture regime level, year, and treated were significant for all traits, wile The interaction between irrigation regimes level and treatments did not show significant differences for all traits at the other hand Interaction between year and treatment only for grain yield and rate of water loss from the flag leaf was significant ($p<0.01$) (Table 2). The lowest rate for TDM and WUE belong to Sardari, Sabalan and Alamut cultivars and the highest values for these traits obtained from Zarrin and shahriar. Sardari with The lowest WUE had the minimum flag leaf primary water loss and the lowest rate of water loss while the Zarrin with the highest grain yield and dry matter had the highest rate of water loss (Fig. 1). Open stomata were due to waste of water and increase the absorption of carbon dioxide as a food reserve. It seem that Sahand variety had the highest rate of primary water content in flag leaf because of the strong root systems (distribution, density and water absorption efficiency) and in addition after sahand with highest primary water content in flag leaf (capture performance) Zarin showed the maximum rate of water loss from leaf surface (transpiration efficiency) between the cultivars. The results showed that Evapotranspiration efficiency range were between 1.80 gr/kg for Sardary and up to 3.26 gr/kg for the zarin variety (Fig. 1). These amounts in [10] experiment were between the 2.37 to 4.18 gr/kg. He noted that high plant than a shorter one had the higher evapotranspiration performance. [10] found that these amounts were between the 2.37 and 4.18 gr/kg. He noted that higher plant than a shorter one had the higher evapotranspiration performance. WUE and primary water of flag leaf (water capture performance) had a high general heritability and additionally their genotypic coefficient of variation was high as same as (Table 3) which can be useful in breeding genotypes with high WUE [10]. Traits Correlation coefficients with grain yield showed that the water use efficiency had the highest correlation coefficient (0.99) (Table 4) and modified that high water use efficiency cultivars can lead the genotypes with high yield potential. Special Physiological characteristics purpose such as water use efficiency which have positive and significant correlation with yield and unlike have the high heritability of performance May be effective in direct selection for yield performance thus The water use efficiency, evapotranspiration efficiency and total dry matter had a positively correlated with yield performance (Table 4). In addition, water use efficiency, total dry matter and evapotranspiration efficiency are also had very high correlation with grain yield respectively and evapotranspiration efficiency were highly significant correlation with total dry matter (Table 4).

Table 2. Variance analysis of wheat genotypes traits under four irrigation regimes in two years

S.V	df	Yield (g/m^2)	Total dry matter (g/m^2)	HI (%)	WUE	Evapotranspiration efficiency (gr/kg)	Rate of water loss (gr/gh)	Flag Leaf primary water (gr/gr)
year	1	81130.21	310516.07	2837.74	2.98	76.17	0.001	0.26
Irrigation regime	3	317224.95	1785523.90	274.86	0.24	1.35	0.008**	0.34**
Year * irrigation regime	3	137072.21**	721734.85**	140.48	1.47**	7.72**	0.001	0.01
replication	24	7352.30**	38630.69	28.45	0.054**	0.31	0.001	0.005
treatment	6	46162.71	261667.07	146.48**	0.30	1.77	0.004	0.24**
Year * treatment	6	28650.29**	200249.98	39.93	0.16	1.42	0.001**	0.02
Irrigation regime * treatment	18	7729.87	86628.23	83.43	0.07	0.74	0.001**	0.017
Year * irrigation regime* treatment	18	22794.52**	107224.60**	140.23**	0.18**	075**	0.001	0.016**
Error	144	3175.65	23105	26.92	0.02	0.18	0.001	0.005
%CV		17.98	17.65	14.27	19.03	18.66	20.53	19.10

**, **: Indicate significant differences at levels 0.05 and 0.01, respectively.*

Table 3. Heritability, genetic and phenotypic variances associated with the changes in bread wheat under four water regimes during two growing seasons

Treats	means	Genotype variance	Phenotype variance	Phenotypic variation coefficient	Genotype variation coefficient	General heritability
Yield (g/m^2)	313.42	52.076	3696.41	19.39	7.28	0.14
Total dry matter (g/m^2)	860.98	4686.87	27791.87	19.36	7.59	0.16
HI (%)	36.36	1.40	27.92	14.53	3.25	0.05
Water use efficiency (WUE)	0.804	0.005	0.02	20.92	9.11	0.18
Evapotranspiration efficiency(gr/kg)	2.27	0.028	0.20	20.07	7.36	0.13
Rate of water loss (gr/g h)	0.053	0.0001	0.001	1.98	0.20	0.05
Flag leaf primary water (gr/gr)	0.355	0.006	0.011	30.07	22.53	0.56

Various researchers were also reported a positive significant correlation between the total dry matter and WUE [11,12,13]. High genotypic coefficient variation and heritability of the trait were due to controlling by a few genes with large effects [2]. [14] were reported the highest correlation for yield and WUE (99%). In order to realize the direct and indirect effects of traits on grain yield and to separate the components of the correlation coefficients, path analysis was performed. Path analysis of traits with grain yield showed that water use efficiency had the direct and higher effect (0.6) on the yield (Table 5), because with the increased in WUE and keeping other variables constant, grain yield will be increased. Indirect effects can neutralize the direct effect. The highest indirect effects of these traits on the grain yield were come from total dry matter with average 0.55 and 0.29, respectively. The genotypes with high WUE had High dry matter and also were had a high grain yield. Ehdaie reported that [10] genotype with high dry matter were also mainly taller than other which often had high WUE, In this study Zarin with high total dry matter had high water use efficiency but in the case of Sardari had no such feature. After water use efficiency parameter ,total dry matter with average 0.316 had the highest direct effect on grain yield and High photosynthetic capacity and remobilization of photosynthetic accumulation from stem reserves to grain at grain filling period were cause high dry matter and could be due to increase the yield (Table 5).

Flag leaf water loss rate had direct and indirect effects on grain yield and also were had minimal and negative values on grain yield. At the other hand simple correlation function of Flag leaf water loss rate had the positive and non-significant (0.58). Simple correlation interactions ,regardless of the cause and effect relationship while the path analysis after establish the relationship of the causal between variables indicate their relative importance. Similar results of Path analysis and correlation of traits showed that water use efficiency had the most direct effect between traits Therefore it could be considered as an indirect selection criterion for utilize grain yield performance in breeding programs. Furthermore ,this trait were had high heritability and genotypic coefficient of variation which can be used as identification for parents of hybrids in programs. High importance of WUE and effected on grain yield , cause to degradation of these trait to component such as performance of evapotranspiration and harvest index. The results showed that most water use efficiency in wheat variety directly affected by the evapotranspiration efficiency ($p<0.05$). (Fig. 2) High evapotranspiration were caused to increase carbon dioxide absorption and increase of food reserves that will ultimately lead to increased grain yield performance and A linear genetic gain in grain yield (for different cultivars) has been positively correlated with both harvest index (HI) and above-ground mass [15]. These models can be divided to elements such as Water use efficiency (ratio of grain yield to total water used) = water uptake efficiency (transpiration water ratio / total water used) × transpiration efficiency (total dry matter ratio to transpiration water) × harvest index (ratio of grain yield to total dry matter). Absorption efficiency of the plants was defined as ability to absorb water from the soil and reduce evaporation. Absorption efficiency related to root traits ,early growth treatment, length , diameter and root distribution ,size of the vascular system ,canopy temperature [16,5] and osmotic adjustment that were related to root growth ability to extract excess water from the soil [17]. Decrease water evaporation from the soil surface portion available water for the plant transpiration. Sahand variety because of the maximum amount of primary water in the leaf seems to have been the high water absorption And Sardari has minimal water absorption (Figure 1). Furthermore ,the water uptake efficiency by plant roots is dependent on transpiration water from the plants surface .Each factor that was increased transpiration efficiency would increase the absorption efficiency. [14] Reported that cultivars with high harvest index had minimum water evaporation from the soil due to rapid initial growth rate. Also transpiration efficiency in local wheat variety populations was similar. Transpiration

Efficiency depends on the number and size of leaf and stomata, leaf angle ,relative growth rate of the plants, solar radiation absorption and decrease in surface evaporation, shading of the canopy [18,16,5] ,the leaf waxy structure, fluff in the leaf, closed canopy and existence of awn [19]. Highest water losses observed from zarin and minimum were belonging to Sardari cultivar (Fig. 1). Genetic differences among cultivars with rapid water loss (transpiration efficiency), could be due to differences in transpiration system performance or assimilation performance. In this model estimate the evapotranspiration water were difficult to separate and in field experiments condition evapotranspiration efficiency are studied simultaneously. However high evapotranspiration efficiency singly could not lead to higher grain yield performance. Several researches show that [14,5] changes in the absorption efficiency of wheat genotypes were due to changes in transpiration efficiency and lower harvest index. In this study ,changes in flag leaf primary water content (absorption efficiency) were lower than water loss (transpiration efficiency) and harvest index (Fig. 2). Genetic diversity among wheat varieties for WUE may be due to transpiration efficiency (rapid water loss) because harvest index and evapotranspiration efficiency due to merger of transpiration and evaporation were not show a significant difference. Furthermore, it seems that water use efficiency was indirectly affected because of total dry matter significant. Rate of evaporated water from the soil determine by the rapid growth of the seedlings, the placement of the leaves and reduced canopy were influenced so exposed much water for plant transpiration. It seems that zarin, in addition to have these traits were also had a high water use efficiency (Fig. 1). Introduction of dwarf varieties, with fewer tillers and higher grain filling period (early heading) that cause increase in soluble sugars storage in the grain and decrease in proportion of structural carbohydrates were had the several methods for overcome the harvest index reduction. Each of these highly heritable traits can be controlled by a few genes and reduce the vegetative organs growth [20]. In this study, compared new improved varieties such as zarin and shahriar with the old cultivars (Sardari) showed that they had higher harvest index.

Table 4. Correlation coefficients of bread wheat under four water regimes during two growing seasons

Treats	Yield (g/m^2)	Total dry matter (g/m^2)	HI %	WUE	Evapotranspiration efficiency (g/gh)	Rate of water loss (g/kg)
Total dry matter(g/m^2)	0.93**					
HI (%)	0.68	0.40				
Water use efficiency (WUE)	0.99**	0.93**	0.65			
Evapotranspiration efficiency (g/kg)	0.95**	0.97**	0.43	0.95**		
Rate of water loss (g/g h)	0.58	0.48	0.41	0.52	0.54	
Flag leaf primary water (gr/gr))	0.39	0.29	0.28	0.31	0.35	0.95**

*** - indicate Significant at 0.01 probability*

Table 5. The direct effect (element diameter) and indirect effect on grain yield in bread wheat cultivar under four water regimes during two growing seasons

Treat	Total dry matter (g/m^2)	HI %	WUE	Evapotranspiration efficiency (g/kg)	Rate of water loss (g/kg)	Flag leaf primary water (gr/gr)
Total dry matter(g/m^2)	0.316	0.126	0.293	0.3065	0.1516	0.0916
HI (%)	0.0592	0.148	0.0962	0.0636	0.0606	0.0414
Water use efficiency (WUE)	0.558	0.39	0.6	0.57	0.312	0.186
Evapotranspiration efficiency (g/kg)	0.00873	0.00387	0.00855	0.009	0.00486	0.00315
Rate of water loss (g/gh)	- 0.0547	- 0.0467	- 0.0592	-.0615	- 0.114	- 0.1083
Flag leaf primary water (gr/gr)	0.0493	0.0476	0.0527	0.0595	0.1615	0.170

R^2 = 1.00

These models can be divided to elements such as Water use efficiency (ratio of grain yield to total water used) = water uptake efficiency (transpiration water ratio / total water used)× transpiration efficiency (total dry matter ratio to transpiration water) × harvest index (ratio of grain yield to total dry matter). Absorption efficiency of the plants was defined as ability to absorb water from the soil and reduce evaporation. Absorption efficiency related to root traits ,early growth treatment, length ,diameter and root distribution ,size of the vascular system ,canopy temperature [16,5] and osmotic adjustment that were related to root growth ability to extract excess water from the soil [17]. Decrease water evaporation from the soil surface portion available water for the plant transpiration. Sahand variety because of the maximum amount of primary water in the leaf seems to have been the high water absorption And Sardari has minimal water absorption (Fig. 1). Furthermore ,the water uptake efficiency by plant roots is dependent on transpiration water from the plants surface .Each factor that was increased transpiration efficiency would increase the absorption efficiency. Similar work done by [14] and reported that cultivars with high harvest index had minimum water evaporation from the soil due to rapid initial growth rate. Also transpiration efficiency in local wheat variety populations was similar. Transpiration Efficiency depends on the number and size of leaf and stomata, leaf angle ,relative growth rate of the plants, solar radiation absorption and decrease in surface evaporation, shading of the canopy [18,16,5] the leaf waxy structure, fluff in the leaf, closed canopy and existence of awn [19]. Highest water losses observed from zarin and minimum were belonging to Sardari cultivar (Fig. 1). Genetic differences among cultivars with rapid water loss (transpiration efficiency), could be due to differences in transpiration system performance or assimilation performance. In this model estimate the evapotranspiration water were difficult to separate and in field experiments condition evapotranspiration efficiency are studied simultaneously. However high evapotranspiration efficiency singly could not lead to higher grain yield performance. Several researches show that [14,5] changes in the absorption efficiency of wheat genotypes were due to changes in transpiration efficiency and lower harvest index. In this study, changes in flag leaf primary water content (absorption efficiency) were lower than water loss (transpiration efficiency) and harvest index (Fig. 2). Genetic diversity among wheat varieties for WUE may be due to transpiration efficiency (rapid water loss) because harvest index and evapotranspiration efficiency due to merger of transpiration and evaporation were not show a significant difference. Furthermore, it seems that water use efficiency was indirectly affected because of total dry matter significant. Rate of evaporated water from the soil determine by the rapid growth of the seedlings, the placement of the leaves and reduced canopy were influenced so exposed much water for plant transpiration. It seems that zarin, in addition to have these traits were also had a high water use efficiency (Fig. 1). Introduction of dwarf varieties, with fewer tillers and higher grain filling period (early heading) that cause increase in soluble sugars storage in the grain and decrease in proportion of structural carbohydrates were had the several methods for overcome the harvest index reduction. Each of these highly heritable traits can be controlled by a few genes and reduce the vegetative organs growth [20]. In this study, compared new improved varieties such as zarin and shahriar with the old cultivars (Sardari) showed that they had higher harvest index.

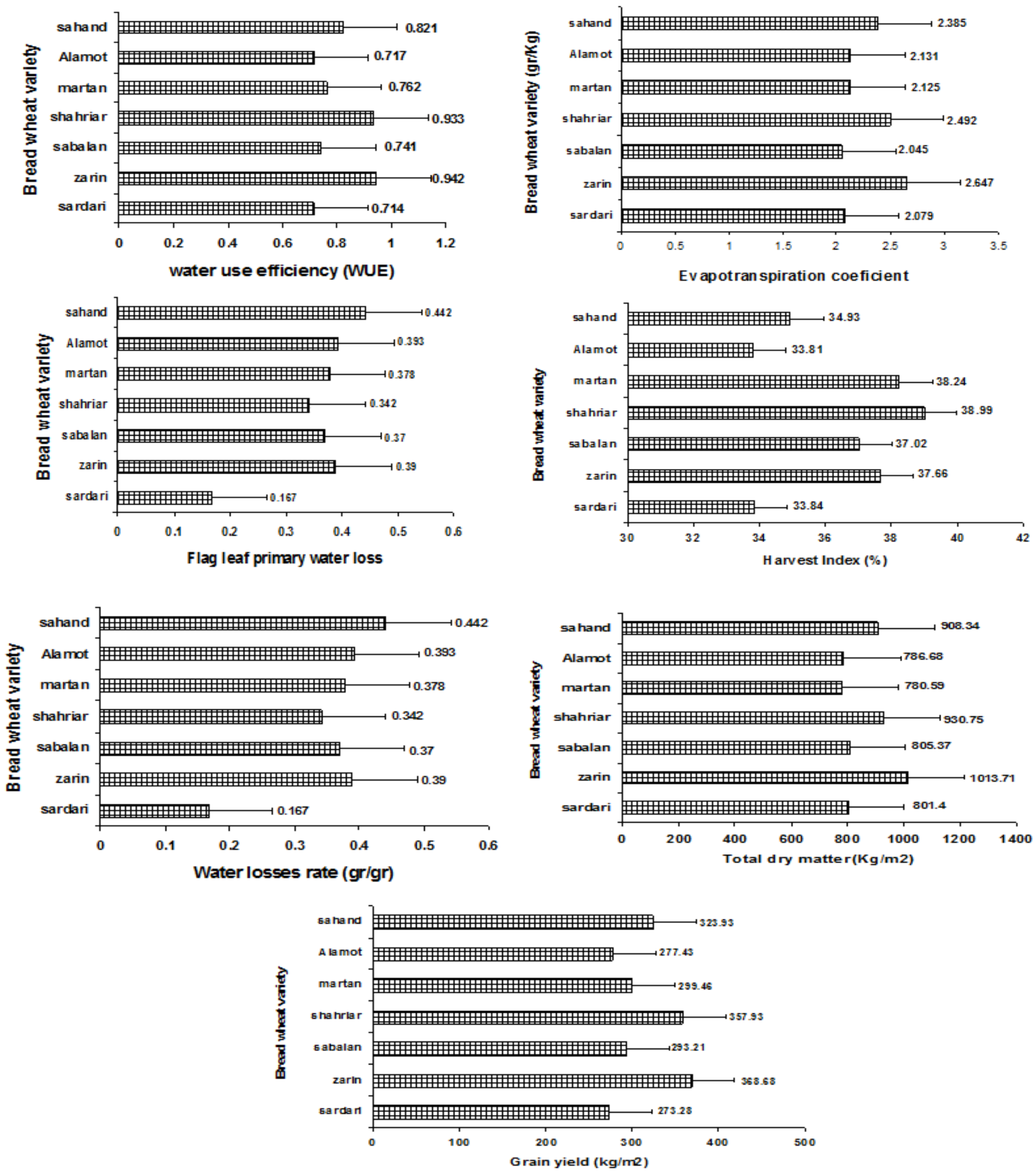

Fig. 1. The average yield of wheat cultivars under four irrigation regimes and crop year

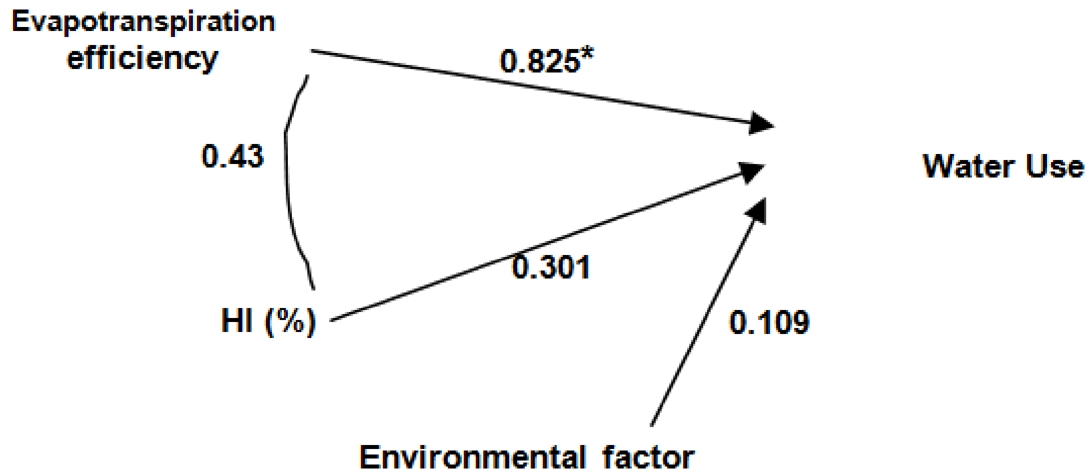

Fig. 2. Path analysis of yield components and water use efficiency in wheat under four water regimes during two growing seasons

4. CONCLUSION

Plant breeders In order to optimize the use of inputs and genetic diversity, were required a genotypes with high WUE.To increase water use efficiency under field condition researchers should increase transpiration efficiency and harvest index. It has been adjusted to maximum level in modified crops. A linear genetic gain in grain yield (for different cultivars) has been positively correlated with both harvest index (HI) and above-ground mass [15]. Integration traits such as evapotranspiration performance and high harvest index in one genotype were effective steps to improve water use efficiency and increase grain yield. Recently, a lot of researches showed that supernumerary water supply resulted decreasing both in grain yield and water use efficiency [11,2,21,22]. In breeding programs and about agronomy use some methods to increase water use efficiency of wheat such as consumption fertilizers (which increases transpiration efficiency) and livestock (which increase soil water storage capacity), Fertilization in dry land can increase the use of soil moisture, and improve wheat yields to some extent. Fertilizer application has been reported to have a beneficial effect on improving WUE and grain yield of spring wheat [23]. At the other hand Improve the plant density and row spacing, mulch application, variety selection base on cultivar rapid primarily growth, plowing (that increase soil permeability), fallow, intercropping, choose varieties with deep roots, changing sowing dates (starts canopy improvement before the cold season) Supplemental irrigation, water collection, control of pests and diseases, increasing the concentration of carbon dioxide in the atmosphere (transpiration efficiency increases), try to use crops such as canola and Indian mustard in rotation that known as Break crops and they were triggered cycle of cereal root diseases.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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