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The Effect of Complementary Irrigation in Growth Stages on Yield, Qualitative and Quantitative Indices of Wheat (*Triticum aestivum* L.)

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Abstract: In most wheat growing moderate regions and especially in the north of Iran climate, is affected grain filling period by several physical and abiotic stresses. In this region, grain filling often occurs when temperatures are increasing and moisture supply is decreasing. The study was carried out in Agricultural Research farm, Jouybar Branch in 2007-2008. Four irrigation treatments included (I_0) no irrigation (check); (I_1) one irrigation (50 mm) at heading stage; (I_2) two irrigation (100 mm) at heading and anthesis stage; and (I_3) three irrigation (150 mm) at heading, anthesis and early grain filling growth stage, two wheat cultivars (Milan and Shanghai) were used the experiment. Totally raining was 453 mm during the growth season. The results indicated that biological yield, grain yield and harvest index were significantly affected by irrigation levels. I_3 treatment produced more tillers number / m^2, fertile tillers number / m^2, harvest index and biological yield. Milan cv. produced more tillers number / m^2, fertile tillers / m^2, while Shanghai cv. produced heavier tillers and 1000grains weight. Plant height was significant in wheat varieties, while were not statistically significant under irrigation levels. Milan produced more grain yield, harvest index and biological yield. Grain yield 5228 (21%), 5460 (27%) and 5670 (29%) kg ha^{-1}, under I_1, I_2 and I_3, respectively. There was an interaction of irrigation and cultivars on grain yields. In the absence of the irrigation 1000 grains weight was reduced from 45 to 40 g. No irrigation reduced soil moisture extraction during the grain filling stage. It is concluded from research work that wheat crop irrigated Milan cultivar could increase the grain yield in comparison with Shanghai cultivar. Although, the grain yield of Shanghai under irrigation was slightly lower than Milan. The best result was produced by I_1 treatment. I_2 and I_3 treatments were not significantly difference with I_1 treatment. Therefore, I_1 irrigation was better than I_0.

Key words: Wheat · Anthesis · Supplementary irrigation · Grain yield

INTRODUCTION

The Mazandaran of North Iran is a vast, semi humid area with mean annual precipitation ranging from 600 to 900 mm. About 80% of the annual precipitation occurs from October through March. The prevailing cropping systems are continuous winter wheat systems. Continuous winter wheat systems are seeded around October and harvested around June. The severe water stress that normally occurs in this region significantly lowers yields. In this region, rain is falling mainly during the winter and a lesser amount during the warmer spring period. This rainy season is followed by a hot, dry spring. Tahmasebi Sarvestani *et al*. [1] showed that irrigation at planting plus milking stages produced the highest yield compared with irrigation at milking stage. Among genotypes Sabalan genotype with average yield of 2213 kg/ha produced the highest and Sardari genotype with 1502 kg/ha had the lowest grain yield. In general supplemental irrigation caused an increment of 36 percent yield of Sabalan genotype. Li *et al*. [2] reported that available soil water for winter wheat was depleted gradually beginning in May and continuing until the beginning of the rainy season in late June. Low precipitation period from April through June also makes it difficult to establish a good wheat stand. In years when there is sufficient available soil water at the wheat planting time or when the rains occur early in the spring season at a critical growth stage, winter wheat yield can be above mean (3 Mg ha^{-1} for wheat) [3]. Increase production depends to a great extent on further improvement of soil water availability and efficient water

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use [4]. Although water deficits are unavoidable in the dry environment, studies have shown that water stress effects can be minimized by management practices that increase available soil water at planting or by supplemental irrigation [5-7]. Several studies have shown that supplemental irrigation at critical growth stages can mitigate the effects of crop water stress on yield [8-12]. Other study in China has advanced rainwater-harvesting technologies to provide a water source for supplemental irrigation [13-14]. Efficiency of water supplement in comparison with full water at growth period of plant is reported from 60 to 70 percent in some countries [15]. Siadat (1987) [16] reported that means of increasing wheat and barley grain yield under supplemental irrigation are 1175 and 1088 kg/ha, respectively. Increasing grain wheat yield under supplemental irrigation was reported about 1 ton /ha in Pakistan [15]. Siadate, [16] reported that wheat grain yield was increased to 1748 kg/ha by using two times of supplemental irrigation at producing spike and milking stages in Kermanshah, while increasing yield with one irrigation in each above stages was 1500 kg/ha. Supplemental irrigation is defined as the application of a limited amount of water to rainfed crops when precipitation fails to provide the essential moisture for normal plant growth. This practice has shown potential in alleviating the adverse effects of unfavorable rain patterns and thus improving and stabilizing crop yields [17-19]. Early studies at ICARDA showed that applying two or three irrigations (80–200 mm) to wheat increased crop grain yield by 36 to 450% and produced similar or even higher grain yields than in fully irrigated conditions [17, 20]. Supplemental irrigation is widely practiced in Syria and in southern and eastern Mediterranean countries. However, excessive use of water in supplemental irrigation because of low irrigation cost and attractive gains from increased yields has resulted in a decline of aquifers and deterioration of water quality in many areas [21]. So, the amount of rainwater that can be harvested is small relative to the area of wheat grown under water-stressed conditions. Rainfed crop production under this climate thus depends strongly on both the amount and distribution of rain. In north region, the amount of rainfall is high and generally poorly distributed, so periods of water deficit occur during the grain-filling stage of wheat almost every year. The objectives of this study were (i) to evaluate how complementary irrigations can be combined to further enhance the use of limited water resources and (ii) to determine the effectiveness of complementary irrigation methods for increasing grain yield.

MATERIALS AND METHODS

Field experiment was conducted at the Mazandaran in farm research at Jouybar (55°11'E, 36°38'N 10 m altitude) in 2007 in the North of Iran. The site is typical lowland with the humid climate of wide seasonal variations. Precipitation distribution and totals had large differences between years. The amounts of seasonal rainfall received from planting to harvest were around 500 mm. Seventy to eighty percent of it occurs as thunderstorms during the October through April period. The greatest difference between the potential ET and precipitation occurs between May and June and this is a critical period for winter wheat growth (Table 1). The soil is loam and 0.8% soil organic matter (Table 2). Split-plot, in randomized block design with four replications was used. Irrigation treatments included (I_0) no irrigation (check); (I_1) one irrigation (50 mm) at heading stage; (I_2) two irrigation (100 mm) at heading and anthesis stage; and (I_3) three irrigation (150 mm) at heading, anthesis and early grain filling growth stage. Description of Zadoks' wheat development scales; first spikelet of inflorescence (ZS=50), beginning of anthesis (ZS=60) and early milk (ZS=70). The treatments comprised two bread wheat (*T. aestivum* L.) cultivars were used (Milan and Shanghai).

Table 1: Mean, maximum and minimum temperature, rain and evapo-transpiration in 2007-2008

Variable	Nov.	Des.	Jan.	Feb.	Mar.	Apr.	May	Jun.
Min. temperature	12.3	4.9	1.8	4.7	4.6	9.2	13.6	20.2
Max. temperature	22.6	12.9	12.3	14.8	13.9	16.3	21.8	31.0
Mean temperature	16.9	8.6	8.3	9.4	8.7	12.8	17.7	25.6
Precipitation	91.0	90.3	118.6	67.9	58.7	52.6	16.6	13.5
Evapotranspiration	63.1	35.1	25.4	35.7	51.4	55.5	93.7	166.6

Table 2: Selected soil properties for composite samples at experimental site in 2007-2008

Soil texture	CEC meqi	K ppm	P ppm	Total Nitrogen %	OM %	pH	EC µmhos/cm	Depth cm
Loam	4.8	168.37	16.5	320	0.78	7.52	1.4	0-20
Loam	5.9	78.23	8.8	185	0.38	7.78	1.7	20-40

Wheat cultivars were the main plots and SI the subplots. The area of individual sub-plots was 8 m^2 (2m x 4m). Therefore, there were 32 plots. The plots were divided into 1-m strips on about 19 Nov. and the plots were broadcast-fertilized with 150 kg N ha^{-1} as urea and 100 kg P ha^{-1} as triple super phosphate (46% P_2O_5)and 100 kg K ha^{-1} as sulfate potassium(46% K_2O). Nitrogen application (urea) was split; half at planting, 25% top-dressed at the early tillering stage and 25% at the Jointing. Phosphorus and potassium were applied as basal dressing. The wheat rows were planted in 15 cm rows at a seed rate of approximately 300 seeds m^2.

Precipitation was measured daily at a weather station 3 km from the experimental field. Grain yields for experiment were determined by hand-harvesting 3 m^2. Grains were harvested in each plot using a combine harvest. Grain samples were air-dried on concrete, threshed, oven-dried at 70°C to a uniform moisture level and weighed. Irrigation system was designed to ensure full and uniform water coverage and distribution. Irrigation was applied to all treatments at the same time. The obtained data was analyzed using a split-plot, unbalanced ANOVA for data. Main plots were wheat cultivars and subplots were irrigation in plant growth stage at irrigation. Experiment was analyzed as a randomized complete block design. The Duncan multiple range test (P = 0.05) was used to test the treatment means. Analyses used procedure of the SAS statistical software package (SAS Inst., 1991) [22].

RESULTS AND DISCUSSION

The results indicated that biological yield, grain yield and harvest index were significantly affected by irrigation levels. Milan cv. produced more grain yield, harvest index and biological yield. Grain yield shown that I_1, I_2 and I_3 produced increasing of 5228 (21%), 5460 (27%) and 5670 (29%) kg ha^{-1}, respectively. There was an interaction of irrigation and cultivar on grain yields. Small amounts of complementary irrigation applied to wheat significantly increased grain yield. Grain yield values varied between crop from 3825 kg/ha for non irrigated wheat to 5963 kg/ha for plots receiving 150 mm of complementary irrigation. The greatest mean grain yield value was 5670 kg/ha when 150 mm of supplement irrigation was added at the three stage and the lowest was 4032 kg/ha in the check. The biological yield was the greatest when complementary irrigation was applied during three growth stages. Straw yield was mostly greater than the grain yield values. Pierre *et al*. [23] indicated that biomass reductions under water stress tended to be higher if plots received high N fertilization. When complementary irrigation was applied at heading stage, grain yield were always higher than the check, particularly when the averaged respective supplement irrigation were I_0 compared with only I_1. Results for yield suggested that adding small amounts of complementary irrigation during heading stage can be highly effective for increasing yields and that I_1 can be 30% greater than the check. The first irrigation was

Table 3: Analysis of variance data for plant height, tiller number, fertile tiller biological, straw and grain yield, GTW, HI, in wheat

ANOVA	D.F.	Grain yield	Biological yield	Straw yield	Harvest index	GTW	Plant height	Tiller N.	Fertile tiller N.
Rep.	3								
Cul. (A)	1	**	ns	ns	*	**	**	**	**
E (a)	3								
Irri. (B)	3	**	**	**	*	**	Ns	**	*
A×B	3	*	*	*	*	ns	Ns	*	*
E (b)	18								
C.V. (%)	-	9.3	13.1	18.2	7.9	13.8	17.8	18.3	14.8

* and **: significant at the 5% and 1% levels, respectively. ns: non significant

Table 4: Effect of supplemental irrigation on plant height, yield and yield components of wheat in 2007

Treat.	Grain yield Kg/ha	Biological yield Kg/ha	Straw yield Kg/ha	Harvest index %	GTW g	Plant height cm	Tiller numbers m^2	Fertile tiller numbers m^2
I_0	4032c	9042c	5010c	44.5b	40.2c	96a	341c	322c
I_1	5228ab	1054ab	5315b	49.6a	43.8ab	98a	489b	450b
I_2	5460a	10975a	5515ab	49.7a	44.2ab	100a	598a	512a
I_3	5670a	11595a	5925a	48.9a	45.3a	101a	678a	551a
Mi.	5364a	10729a	5365a	49.9a	45.3b	90b	586a	518a
Sh.	4830b	10347a	5517a	46.7b	48.2a	106a	465b	399b

applied around the time of heading in early April. After anthesis, 1000 grains weight under complementary irrigation was significantly greater than that under rainfed conditions. Pierre *et al*. [23] showed that water stress reduced grain yield and kernel weight. Grain 1000 weight was significantly influenced by complementary irrigation and cultivars and most of the interactions. Complementary irrigations significantly (P <0.01) increased biological yield for grain yield but not for straw yield. The highest tiller numbers was achieved at I_2 in Shanghai cv. and I_3 in the Milan cv.. Plant height in Shanghai consistently resulted in higher biological yield but not for grain yield than plant height in Milan. This is clearly associated with the substantial increase in grain and biological yields with complementary irrigation. However, there were good linear relationships between grain and biological yields with complementary irrigation. Harvest index for complementary irrigation ranged from 44.5 to 49.7%, depending on the complementary irrigation level and cultivar. The HI was increased with increasing irrigation in the Milan and Shanghai cvs, but there was no further increase for the I_3. non irrigation generally decreased grain yield and plant height. The highest tiller numbers was achieved at complementary irrigation for Milan cv.. Tiller numbers and effective tiller numbers significantly increased with increasing the amount of irrigation during growth stages. The average grain yield was increased from 4032 to 5228 kg/ha when initial water use increased from 0 to 50 mm. The complementary irrigation applied during heading, anthesis and early grain filling growth stages resulted in a maximum grain yield. Plant height was significant in wheat varieties, while were not statistically significant in irrigation levels. Plant height was increased from 96 to 101 cm with increaseing the irrigation water from 0 to 150 mm. This study shows that the maximum yield of wheat was obtained when a complementary irrigation was applied during heading stage. Milan cv. produced more tillers numbers / m^2, fertile tillers in / m^2, while Shanghai cv. produced heavier 1000 grains weight. In the absence of the irrigation reduced 1000 grains weight from 45 to 40 g. No irrigation reduced soil moisture extraction during the grain filling stage. Current assimilation as a source of carbon for grain filling depends on the light intercepting viable green surfaces of the plant after anthesis that due to natural senescence and the effect of various stresses. At the same time the demand by the growing grain is increasing. Treatment I_3 produced more tiller numbers / m^2, fertile tillers numbers / m^2, harvest index and biological yield. So, the best result was produced by using I_1 treatment. Irrigation treatments I_2 and I_3 were not significantly difference with I_1 treatment. Grain yield of I_1 was reduced under soil moisture stress. Therefore, I_1 irrigation was better than I_0. In the rainfed farming systems of the Mazandaran region, where water supply is often limited due to high rain, agronomic practices should aim to utilize the water available for crop growth in an efficient way. Improving the production from limited water supply can result from increasing the total amount of water used by the crop through complementary irrigation and improving the efficiency of water use through the adoption of irrigation deficit. Supplemental irrigation at or after anthesis not only allows the plant to increase its photosynthesis rate (Passioura, 1976) [24] but, more importantly, gives the plant extra time in which to translocation carbohydrate reserves to the grain [25]. These values are comparable to those found under greenhouse conditions [26] and under field conditions in South Australia [27]. The increase in water use efficiency under supplemental irrigation is associated with increasing leaf area and its effect on the ratio of soil evaporation to crop transpiration [25] and increased root growth and its effect on water extraction [28]. This work showed that the common practice of complementary irrigation, which aims at satisfying full irrigation requirements, is not the most efficient in water use for the Mazandaran rainfed environment. Applying I_1 of the complementary irrigation requirements, during and after anthesis, substantially improve irrigation water productivity. The loss in yield due to irrigation deficit is small compared with the savings in irrigation water. If this is combined with an early sowing and adequate N application, a high yield may be achieved, in addition, up to 25% of the grain yield can be increased for expansion of the area irrigated. Angus and Herwaarden, [29] showed that the differences between the efficiencies for the total dry matter and grain was due to an accumulation of cellulose in the stems during grain filling. Finally, current assimilation as a source of carbon for grain filling depends on the light intercepting viable green surfaces of the plant after anthesis that due to natural senescence and the effect of various stresses. At the same time the demand by the growing grain was increased.

Within each treatment, means followed by different letter in a column are significantly different at the 0.05 probability level.

CONCLUSION

Wheat grown in the semi humid area of Iran often suffers seasonal water stress that results in lower grain yields. Complementary irrigation had a significant effect on grain yield of winter wheat grown in soil particularly when small amounts of water are added at critical growth stage. In this study, portion of grain yield from biological yield were greater than straw yield and about 50% or greater for the complementary irrigation winter wheat. The use of complementary irrigation was highly effective in increasing grain yield. Complementary irrigation using a small amount of water at a critical time is an efficient practice to mitigate water stress and increase yields. However, available water for irrigation is not limited in humid areas and practices for increasing yield at time of seeding are highly desirable. However, this study showed that complementary irrigation greatly increased the amount of water used by the wheat and resulted in an increased grain yields. In the regions, complementary irrigation at heading was more important for winter wheat than for check because relatively high amounts of rainfall normally occur during the wheat growing season in contrast to the usually dry conditions for the latter portion of the wheat growing season. The study clearly showed that using I_1 much of the soil can greatly enhance soil water storage and increase wheat yield. Thus, intensive farming technologies for grain increase are adopted and practiced. Although the complementary irrigation for grain crops is a labor and capital intensive technology, it was developed and is being applied due to significant yield increases. Angus and Herwaarden, [29] showed that alternative of conserving water for ET after anthesis is a more promising means of increasing yield, despite a lower TE, because transpiration leads directly to an increase grain growth, as Passioura, [24] concluded that wheat crop irrigated Milan cultivar increased the grain yield in comparison with Shanghai cultivar. Although, the grain yield of Shanghai under irrigation was slightly lower than Milan. This grain yield also was related to weather condition, sowing date, plant density and location conditions and management of fertilizers, because there was not significant difference in biological and straw yield.

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