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# Survey on Qualitative and Quantitative Traits of Winter Wheat under Different Irrigation Treatments Using Weighing Lysimeter in North China Plain

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author MHS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AS and POO managed the analyses of the study. Author XX managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

As the world's population increases, water resources for agriculture become more restrictive and efficient water use takes on greater importance. In 2012-2013 experiment, Irrigation treatments were (I1): Irrigation before sowing (60 Liter), (I2): Irrigation before sowing (30 Liter) + before freezing (30 Liter); (I3): Irrigation before sowing (30 Liter) + before freezing (30 Liter) + Irrigation in the beginning of erecting stage (60 Liter) + Irrigation at flowering stage (60 Liter); (I4): Irrigation before sowing (30 Liter) + Irrigation before freezing (30 Liter) + Irrigation at the booting stage (60 Liter) + Irrigation at flowering stage (60 Liter). The weighing lysimeter system is located in National Precision Agriculture Demonstration Station in Xiaotangshang Town of Beijing. The maximum and the minimum LAI was achieved in I3 (5.96), and I1 (5.25), which had meaningful difference with

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each other. The highest grain yield, harvest index, potassium percentage and ash percentage of forage wheat at flowering stage was obtained by I4. The maximum total biological yield, forage protein percentage, seed phosphorus percentage and seed potassium percentage was related to I3, but it had no significant differences with I4. The higher a thousand seed weight was obtained by I4 (34.85 g), followed by I3 (31.93 g), I2 (30.33 g), and I1 (28.76 g). The results from the study indicate that irrigation of winter wheat throughout the booting stage and flowering stage increased grain yield, harvest index, potassium percentage, ash percentage of forage wheat at flowering stage, seed and forage protein percentage. In 2013-2014 experiment, Irrigation treatments were (I1) no irrigation, (I2) irrigation only at jointing stage(60L), (I3) irrigation at jointing(60L) and flowering stage(60L), (I4) irrigation at jointing stage (April 8$^{th}$,60L), 100% flowering stage (April 30$^{th}$,60L), and grain filling period (May 10$^{th}$,60L). The highest spike number per lysimeter was related to full irrigation (I4), but it had no significant differences with other treatments (P>0.05). I4 had obtained the highest grain yield which was 7.55 ton/ha. Grain yield in I1 and I2 was 4.49 ton/ha and 4.65 ton/ha, respectively. The maximum and the minimum harvest index was related to I4 (44.79%) and I2 (37.97%), which had significant differences with each other. Therefore, on the basis of results of these two experiments, it is important to irrigate winter wheat throughout the booting stage and flowering stage in order to achieve higher yield.

*Keywords: Irrigation; winter wheat; qualitative traits; quantitative traits; weighing lysimeter.*

## 1. INTRODUCTION

China is the largest producer and consumer of wheat in the world [1,2,3]. Wheat ranks as the third leading crop in China after rice and maize [4]. Meanwhile, the water supply for plant canopy formation and maintenance becomes a key factor determining the distribution of winter wheat in the arid and semi-arid region [5,6]. Wheat grain yield is the product of heads per square, seeds per head, and seed weight. Using estimates of these parameters, farmers can derive an estimated grain yield potential [7,8]. Winter forages are sometimes considered by forage producers to conserve irrigation water in short water years. Under field conditions, crop growth is dependent on the ability of canopy to intercept incoming radiation, which is a function of leaf area index and canopy architecture and convert it into new biomass [9]. Development of more water-efficient agricultural practices is a key component of strategies for curbing groundwater depletion in the region [10,11,12]. It has high demand for irrigation water because of scarce precipitation during its growing period March to June. Li et al. [1] and Shuyun et al. [13] also noted that water shortage is a major factor in restricitng stable yield. Liu et al. [14] concluded that water shortage could greatly affect the total domestic grain production. The research was designed to evaluate the effects of irrigation treatments on yield and yield components of winter wheat in weighing lysimeter in North China Plain.

## 2. MATERIALS AND METHODS

The weighing lysimeter system is located in National Precision Agriculture Demonstration Station in Xiaotangshang Town of Being (40° 10$^{/}$N, 116° 27$^{/}$E). The system was consisted of 24 lysimeters with 1.0 m*0.75 m*2.3 m (L*W*H). The machine structure of the lysimeter was counter-balanced and the schematic diagram of the lysimeter is shown in Fig. 1. The background soil characteristics of the experimental plot, determined at the beginning of the experiment, were as follows: sand 516 g kg$^{-1}$, total N 102 g kg$^{-1}$, available phosphorus (P) 23.4 mg kg$^{-1}$, exchangeable potassium (K) 98.7 mg kg$^{-1}$, organic matter 13.4 g kg$^{-1}$, pH 7.3 and bulk density 1.43 g cm$^{-3}$ (Table 1). The average of air temperature (℃), and relative humidity average is shown in Fig. 2. The load cells used in the system are NS1-3M2-100Kg with a sensitivity of 1.9951, V/V for the lysimeters and the NS6-2-50 Kg of 1.9969 mV/V for percolation. Graphs show the average of air temperature and relative humidity, respectively. The experimental station field in Xiaotangshang has sandy clay loam texture.

In 2012-2013 experiment, Irrigation treatments were (I1) (Lysimeters 1, 5, 9, 13, 17 and 21): Irrigation before sowing (60 Liter), (I2) (Lysimeters 2, 6, 10, 14, 18, and 22): Irrigation before sowing (30 Liter) + before freezing (30 Liter); (I3) (Lysimeters 3, 7, 11, 15, 19, and 23): Irrigation before sowing (30 Liter) + before freezing (30 Liter) + Irrigation in the beginning of erecting stage (60 Liter) + Irrigation at flowering stage (60 Liter); (I4) (Lysimeters 4, 8, 12, 16, and 24): Irrigation before sowing (30 Liter) + Irrigation before freezing (30 Liter) + Irrigation at the booting stage (60 Liter) + Irrigation at flowering stage (60 Liter). Pre-irrigation was done on 6th Oct. the laid out of experiment was randomized complete block design, repeated six times. The plantation was done on $10^{th}$ Oct in 2012. 500 seeds per each lysimeter were used in each lysimeter. For small lysimeter, to supply N, P and K, 337 g urea, 337 g diamonium phosphate per each lysimeter, and 202 g $K_2O$ per each lysimeter was used, respectively.26.68 g zink sulfate and 2.25 kg chicken manure was also used per each lysimeter. The distance between rows was 15 cm, and the distance between seeds was one cm. Hand weeding was done for weeds management. Lunxuan 987 was used in this experiment. All practices such as control of weeds, pests, and disease were done regularly during period. At physiological maturity all plants per each lysimeter were harvested and the following parameters were recorded: dry leaf weight, dry stem weight, total dry weight, leaf area index, final plant height (cm), spike length (cm), total biological yield (t/ha), the number of spike per lysimeter, the number of seed per lysimeter, grain yield, a thousand seed weight, the number of seed per spike and harvest index. The leaf and stem of samples were separated and placed in a drying oven at 105℃ for 20 min, then dried at 80℃ for 72 h until reaching constant weight. Leaf area was calculated using the following equation:

Leaf area= leaf length × leaf width × 0.78

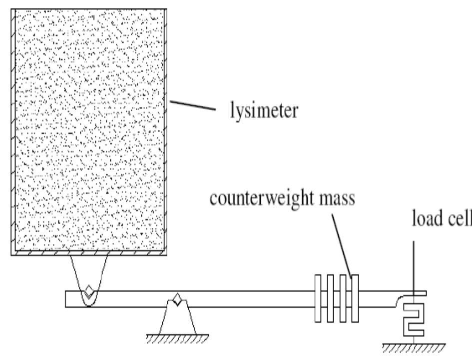


**Fig. 1. The schematic diagram of the weighing lysimeter**

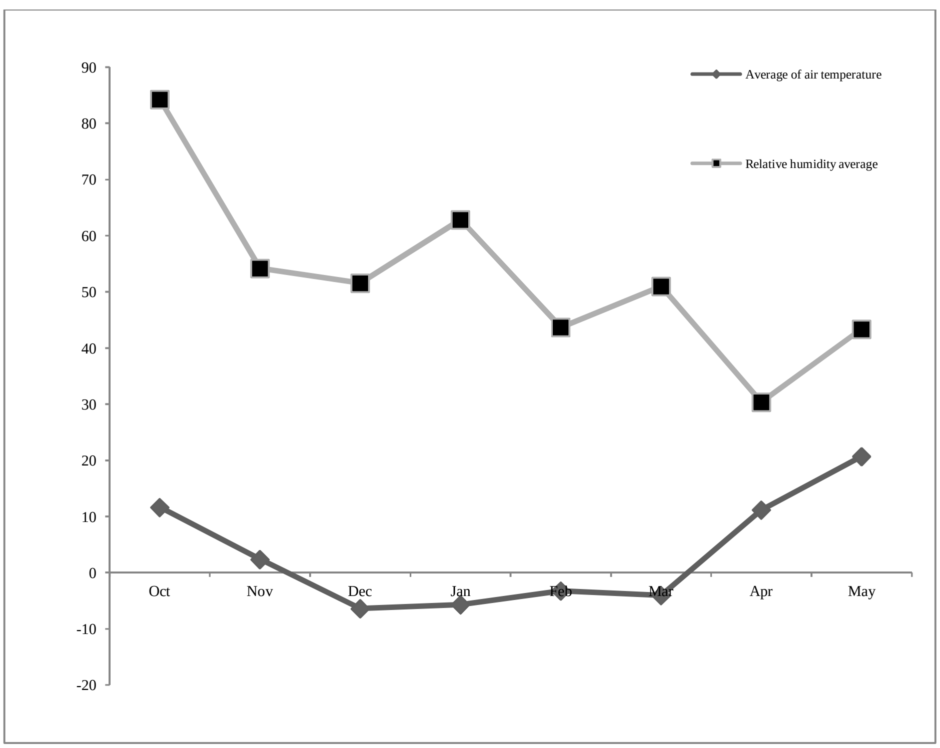


**Fig. 2. The average of air temperature and relative humidity average in 2012**

**Table 1. Mechanical analysis, Ph, total nitrogen, available phosphorus, exchangeable cations and cation exchange capacity of Xiaotanshan**

| Depth (cm) | % sand | % silt | % clay | pH | Total N% | Av. Phosphorus (mg kg-1) | Ca2+ (cmoLkg-1) | Mg2+ (cmoLkg-1) | K+ (cmoLkg-1) | Na+ (cmoLkg-1) | H+ | Al3+ | CE (cmolkg-1) | ECEC (cmolkg-1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 30 | 56.2 | 22 | 21.8 | 7.3 | 0.14 | 47.15 | 16.4 | 4.63 | 0.13 | 0.12 | 0.36 | 1.49 | 22.8 | 23.1 |
| 30- 60 | 30.2 | 30 | 39.8 | 7.1 | 0.06 | 1.4 | 32.3 | 6.72 | 0.19 | 0.59 | 0.16 | 1.49 | 41.31 | 41.5 |
| 60 -90 | 18.2 | 36 | 45.8 | 7.2 | 0.06 | 0.15 | 70.24 | 7.96 | 0.24 | 0.55 | 0.21 | 0.88 | 79.9 | 80.1 |
| 90 -150 | 62.2 | 32 | 15.8 | 7 | 0.03 | 2.2 | 83.3 | 5.28 | 0.03 | 0.36 | 0.16 | 0.67 | 89.7 | 89.9 |

The grains from the plants in each lysimeter was threshed, cleaned and grain yield per lysimeter unit area at moisture content equal to or less than 12%, was determined and converted to kilograms per hectare. The harvest index of each plot was calculated as the ratio of grain yield to biological yield and expressed in percentage. Biological yield was the total weight of dried plant material (leaves, stems, and roots). The amount of nitrogen calculated by Kjeldahl analysis from dry samples, and then nitrogen multiplied by 6.25 to determine protein content of both forage and seed of winter wheat. Ash content determined by incinerating the sample in a muffle furnance at 550℃ for 4 hours. Phosphorus percentage and potassium percentage were calculated by Olsen method and potassium dichromate volumetric methods. In 2013-2014 experiment, Irrigation treatments were (I1) no irrigation, (I2) irrigation only at jointing stage, (I3) irrigation at jointing and flowering stage, (I4) irrigation at jointing stage (April $8^{th}$), 100% flowering stage (April $30^{th}$), and grain filling period (May $10^{th}$). Pre-sowing irrigation was done on $5^{th}$ Oct and irrigation before freezing was done on 23th November 2013. Winter wheat lysimeters were harvested at $6^{th}$ June. Pre-irrigation was done on 6th Oct. the laid out of experiment was randomized complete block design, repeated six times. The plantation was done on $10^{th}$ Oct in 2013. Big lysimeter had 20 lines and 300 seeds were planted for each line (6000 seeds). Each of 24 small lysimeters had 5 lines and 100 seeds per line were planted. 28.12 g/lysimeter Urea, 28.12 g/lysimeter diammonium phosphate, 17 g/lysimeter potassium sulfate, 17 g/lysimeter magnesium sulfate, 2.25 g/lysimeter zink sulfate and 2.25 kg per lysimeter chicken sludge was used for fertilization of small lysimeter. For big lysimeter, 337.3 g urea, 337 g diamonium phosphate, 27 g zink sulfate, 202 g K and 27 kg chicken manure was applied. The row distance of line in big lysimeter was 15 cm. The data on plant parameters were analyzed year wise on individual basis and their means were computed. The laid out of experiment was randomized complete block design, repeated six times. Statistical analyses for ANOVA were carried out by using MSTAT-C, whereas the means were compared through Duncan's Multiple Range Test at (p=0.05) and Excel program to illustrate and compare data on figures. (Jointing stage= 31, Booting stage= 41).

## 3. RESULTS AND DISCUSSION

### 3.1 Experiment 1 (2012-2013)

Irrigation had significant effect on dry stem weight, total dry weight, leaf dry weight/stem dry weight, LAI, final plant height, spike length, total biological yield, number of spike per lysimeter, number of seed per lysimeter, the number of seed per spike, a thousand seed weight, grain yield and harvest index. Irrigation treatment had no significant influence on nitrogen percentage, phosphorous percentage, potassium percentage, ash percentage and protein percentage of winter wheat as forage. Furthermore, irrigation treatment had not significant impact on nitrogen percentage, phosphorous percentage and potassium percentage of winter wheat 's seed. However, straw yield was significantly affected by irrigation treatment. The highest dry stem weight was related to I4, which had not significant differences with I1 and I3, however, its difference with I2 was meaningful. The highest dry stem weight was achieved in I1, followed by I3, I1 and I2. I4 had significant difference with I2, but it had not any meaningful differences with other treatments. I4 had obtained both total dry weight and total dry weight. Its difference was just significant with I2. The higher leaf dry weight/stem dry weight ratio was related to I1, compare to those of other treatments. Leaf dry weight/stem dry weight ratio for I2, I3, and I4 was 0.46, 0.49, and 0.51, respectively. The maximum and the minimum LAI was achieved in I3 (5.96), and I1 (5.25), which had meaningful difference with each other. Both of the mentioned irrigation treatments had not significant differences with I2 and I4. LAI in I2 and I4 was 5.68 and 5.87, respectively. The highest final plant height was achieved in I3 (69.40 cm), followed by I4, I1 and I2. Several investigations from different parts of the world reported that plant height increased with more frequent irrigation and decreased with less frequent irrigation [15]. The highest spike length was obtained by I3 (8.21 cm) followed by I4, I1, and I2. Even though, there were not any significant differences among I1, I2 and I4, I3 had significant differences with all of the treatments. On the one hand, the maximum total biological yield was achieved in I3, which had significant differences with all other treatment, except I4. On the other hand, the minimum one was related to I2 (Table 2).

**Table 2. Mean comparison for experimental characteristics**

| Treatment | Dry leaf weight (kg per lysimeter) | Dry leaf weight (t/ha) | Dry stem weight (kg per lysimeter) | Dry stem weight (t/ha) | Total dry weight (kg per lysimeter) | Total dry weight (t/ha) | Leaf dry weight/stem dry weight | LAI | Final plant height (cm) | Spike length (cm) | Total biological yield (kg per lysimeter) | Total biological yield (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Irrigation levels** | | | | | | | | | | | | |
| I1 | 0.39a | 5.28a | 0.72ab | 9.61ab | 1.11ab | 14.91ab | 0.81a | 5.25b | 57.17b | 7.25b | 1.08b | 14.51b |
| I2 | 0.37a | 4.99a | 0.54b | 7.22b | 0.96b | 12.22b | 0.46b | 5.68ab | 57.16b | 7.24b | 0.98b | 13.11b |
| I3 | 0.34a | 4.62a | 0.75ab | 10.01ab | 1.09ab | 14.63ab | 0.49b | 5.96a | 69.40a | 8.21a | 1.45a | 19.35a |
| I4 | 0.39a | 5.26a | 0.83a | 11.08a | 1.22a | 16.35a | 0.51b | 5.87ab | 68.33a | 7.98b | 1.22ab | 16.29ab |

*Common letter within each column do not differ significantly*

*Irrigation treatments are= (I1): Irrigation before sowing (60 Liter), (I2): Irrigation before sowing (30 Liter) + before freezing (30 Liter); (I3): Irrigation before sowing (30 Liter) + before freezing (30 Liter) + Irrigation in the beginning of erecting stage (60 Liter) + Irrigation at flowering stage (60 Liter); (I4): Irrigation before sowing (30 Liter) + Irrigation before freezing (30 Liter) + Irrigation at the booting stage (60 Liter) + Irrigation at flowering stage (60 Liter).*

The higher number of spike per lysimeter was achieved in I4, followed by I3, I1, and I2. The difference of I4 with I3 was not significant, but it had meaningful difference with I1 and I2. The higher number of seed per lysimeter was related to I3, than those of other treatments. The maximum and the minimum grain yield was obtained by I4 (4.86 t/ha), and I1 (2.87), which had significant differences with each other. The higher a thousand seed weight was obtained by I4 (34.85 g), followed by I3 (31.93 g), I2 (30.33 g), an I1 (28.76 g). I4 had significant difference with I1, but there was not any meaningful difference between I4 and I2 and I3. The maximum and the minimum number of seed per spike was related to I3 (22.75) and I1 (17.98), which had significant difference with each other. Although, the number of seed per spike for I2 was higher than I1 and I4, there were not any significant differences among them. I4 had obtained the maximum harvest index (31.92%). Furthermore, it had not significant difference with I2 and I3, but the difference between I1 and I4 was meaningful. Harvest index in I1, I2 and I3 was 20.58%, 25.14% and 26.92%, respectively. There were not any meaningful differences among I1, I2 and I3 (Table 3). Kang et al. [16], and Ali et al. [17] reported that water management under appropriate irrigation management focuses on efficient use of limited water source, especially in critical plant growths and development. The highest nitrogen and phosphorus percentage of winter wheat as a forage at flowering stage was 1.61% and 0.26%, respectively, which had no significant differences with other irrigation treatments. I4 had obtained the maximum potassium percentage, and its difference with other treatments was not meaningful. The highest and the lowest ash percentage which was 5.59% and 4.67%, related to I4 and I2, respectively. There were not any significant differences among treatments. The higher protein percentage was obtained by I3 (10.11%) followed by I2, I1 and I4, respectively. No meaningful differences were found among irrigation treatments (Table 4). The highest and lowest nitrogen percentage of winter wheat seed was related to I1 (2.91%), and I3 (2.72%), respectively. There are not any significant differences among irrigation treatments. The higher phosphorus percentage was obtained by I3, compare to those of other treatments. There were not any significant differences among irrigation treatments. Phosphorus percentage in I1, I2, I3, and I4 was 0.38%, 0.40%, 0.42% and 0.41%, respectively. The maximum and the minimum potassium percentage was related to I3 (0.62%), and I1 (0.56%), respectively, which had not meaningful difference with each other and other irrigation treatments. Potassium percentage in I2 and I4 was 0.58%, and 0.61%, respectively. The highest seed protein percentage was 18.16%, related to I1. I1 had not any significant differences with other irrigation treatments. Seed protein percentage in I2, I3 and I4 was 17.49%, 17.03% and 17.69%, respectively. No meaningful difference was found among I2, I3 and I4. Seed protein percentage in I2, I3 and I4 was 17.49%, 17.03% and 17.69%. Wang et al. [18] observed that grain yields under irrigation treatments were significantly increased, but the content of grain protein was reduced in wheat. The highest straw yield was achieved in I3 (14.50 t/ha), which had significant difference with other treatments. Although, the lowest straw yield was related to I2 (9.95 t/ha), its difference with other treatments were not meaningful. Straw yield in I1 and I4 was 11.53 t/ha, and 11.52 t/ha, respectively (Table 5).

### 3.2 Experiment 2 (2013-2014)

Spike weight was significantly affected by irrigation treatment. The influence of irrigation treatment on both dry matter dry matter were meaningful. Grain yield and grain yield were meaningfully affected by irrigation treatments. Furthermore, the influence of irrigation treatment on harvest index was significant. The highest spike number per lysimeter was related to full irrigation (I4), but it had no significant differences with other treatments. The maximum spike weight was observed in I3 (irrigation at jointing stage and flowering stage) which was 709.1 g per lysimeter followed by I4, I2 and I1. No meaningful difference was found between I1 and I2 and I4, but I1 had significant differences with I3. There were not any significant differences between I3 and I2 and I4 either. The highest and the lowest dry matter was 16.81 ton/ha and 11.10 ton/ha, which were observed in I4 (irrigation at jointing stage, flowering stage and grain filling period) and I1 (no irrigation). Both I2 and I3 had no meaningful differences with I1 and I4. Dry matter in I2 (irrigation only at jointing stage) and I3 (irrigation at jointing and flowering stage) was 12.17 ton/ha and 14.40 ton/ha, respectively. Full irrigation (I4) had obtained the highest grain yield which was 7.55 ton/ha. I4 had no meaningful differences with I3 (irrigation at jointing stage and flowering stage), but both I3 and I4 had significant differences with I1 and I2. Grain yield in I1 (no irrigation) and I2 (irrigation at jointing stage and flowering stage) was 4.49

ton/ha and 4.65 ton/ha, respectively. Hu et al. [19] concluded that winter wheat biomass accumulation and grain yield in field experiments were influenced by the growing intensity

**Table 3. Mean comparison for experimental characteristics**

| Treatment | The number of spike per lysimeter | The number of seed per lysimeter | Grain yield (g per lysimeter) | Grain yield (kg per ha) | Grain yield (t/ha) | A thousand seed weight (g) | The number of seed per spike | Harvest index (%) |
|---|---|---|---|---|---|---|---|---|
| **Irrigation levels** | | | | | | | | |
| I1 | 439.0b | 7719b | 223.2b | 2976.2b | 2.87b | 28.76b | 17.98b | 20.58b |
| I2 | 396.5b | 7964b | 236.6b | 3155.4b | 2.98b | 30.33ab | 20.13ab | 25.14ab |
| I3 | 499.8ab | 11450a | 263.5ab | 4847.2a | 4.84a | 31.93ab | 22.75a | 26.91ab |
| I4 | 617.3a | 11100a | 357.6a | 4868.4a | 4.86a | 34.85a | 18.15b | 31.92a |

*Common letter within each column do not differ significantly*

*Irrigation treatments are= (I1): Irrigation before sowing (60 Liter), (I2): Irrigation before sowing (30 Liter) + before freezing (30 Liter); (I3): Irrigation before sowing (30 Liter) + before freezing (30 Liter) + Irrigation in the beginning of erecting stage (60 Liter) + Irrigation at flowering stage (60 Liter); (I4): Irrigation before sowing (30 Liter) + Irrigation before freezing (30 Liter) + Irrigation at the booting stage (60 Liter) + Irrigation at flowering stage (60 Liter)*

**Table 4. Mean comparison for forage qualitative traits at flowering stage**

| Treatment | N (%) | P (%) | K (%) | Ash (%) | Protein (%) |
|---|---|---|---|---|---|
| **Irrigation levels** | | | | | |
| I1 | 1.56a | 0.24a | 1.61a | 5.39a | 9.78a |
| I2 | 1.60a | 0.26a | 1.43a | 4.67a | 9.99a |
| I3 | 1.61a | 0.24a | 1.54a | 5.06a | 10.11a |
| I4 | 1.53a | 0.25a | 1.62a | 5.59a | 9.59a |

*Common letter within each column do not differ significantly*

*Irrigation treatments are= (I1): Irrigation before sowing (60 Liter), (I2): Irrigation before sowing (30 Liter) + before freezing (30 Liter); (I3): Irrigation before sowing (30 Liter) + before freezing (30 Liter) + Irrigation in the beginning of erecting stage (60 Liter) + Irrigation at flowering stage (60 Liter); (I4): Irrigation before sowing (30 Liter) + Irrigation before freezing (30 Liter) + Irrigation at the booting stage (60 Liter) + Irrigation at flowering stage (60 Liter)*

**Table 5. Mean comparison for seed qualitative traits at final ripening**

| Treatment | N (%) | P (%) | K (%) | Seed protein percentage (%) | Straw yield (t/ha) |
|---|---|---|---|---|---|
| **Irrigation levels** | | | | | |
| I1 | 2.91a | 0.38a | 0.56a | 18.16a | 11.53b |
| I2 | 2.79a | 0.40a | 0.58a | 17.49a | 9.95b |
| I3 | 2.72a | 0.42a | 0.62a | 17.03a | 14.50a |
| I4 | 2.83a | 0.41a | 0.61a | 17.69a | 11.52b |

*Common letter within each column do not differ significantly*

*Irrigation treatments are= (I1): Irrigation before sowing (60 Liter), (I2): Irrigation before sowing (30 Liter) + before freezing (30 Liter); (I3): Irrigation before sowing (30 Liter) + before freezing (30 Liter) + Irrigation in the beginning of erecting stage (60 Liter) + Irrigation at flowering stage (60 Liter); (I4): Irrigation before sowing (30 Liter) + Irrigation before freezing (30 Liter) + Irrigation at the booting stage (60 Liter) + Irrigation at flowering stage (60 Liter).*

**Table 6. Mean comparison for experimental characteristics**

| Treatment | Spike number per lysimeter | Spike weight (g per lysimeter) | Dry matter (g per lysimeter) | Dry matter (ton/ha) | Grain yield (g per lysimeter) | Grain yield (ton/ha) | HI (%) |
|---|---|---|---|---|---|---|---|
| **Irrigation** | | | | | | | |
| I1 | 476.2a | 436.9b | 833.0b | 11.10b | 337.5b | 4.49b | 39.90b |
| I2 | 499.3a | 572.1ab | 913.2ab | 12.17ab | 349.5b | 4.65b | 37.97b |
| I3 | 504.8a | 709.1a | 1080.0ab | 14.40ab | 464.7ab | 6.19a | 42.84ab |
| I4 | 548.7a | 633.8ab | 1261.5a | 16.81a | 566.9a | 7.55a | 44.79a |

*Common letter within each column do not differ significantly*

*Irrigation treatments were (I1) no irrigantion, (I2) irrigation only at jointing stage, (I3) irrigation at jointing and flowering stage, (I4) irrigation at jointing stage (April 8$^{th}$), 100% flowering stage (April 30th), and grain filling period (May 10$^{th}$)*

water availability during the growing season, and likely by the interaction between factors. The maximum and the minimum harvest index was related to I4 (44.79%) and I2 (37.97%), which had significant differences with each other. No significant differences were found between I1, I2 and I3. Not only I1, but also I2 differences with I4 was meaningful. Harvest index in I3 was 42.84% and it had no significant differences with other treatments, namely I1, I2 and I4 (Table 6).

## 4. CONCLUSIONS

Detection of crop water stress is critical for efficient irrigation water management, especially in the semi-arid regions; moreover, irrigation water is becoming increasingly scares; this high lights the importance of the effective and efficient use of this resource. In 2012-2013, the maximum and the minimum LAI was achieved in I3 (5.96), and I1 (5.25), which had meaningful difference with each other (P<0.05). Both of the mentioned irrigation treatments had not significant differences with I2 and I4 (P>0.05). The highest final plant height was achieved in I3 (69.40 cm), followed by I4, I1 and I2. The highest grain yield, harvest index, potassium percentage and ash percentage of forage wheat at flowering stage was obtained by I4. The maximum total biological yield, forage protein percentage, seed phosphorus percentage and seed potassium percentage was related to I3, but it had no significant differences with I4 (P>0.05). The maximum and the minimum grain yield was obtained by I4 (4.86 t/ha), and I1 (2.87 t/ha), which had significant differences with each other. The difference between I1 and I2 was not meaningful. I3 also had not significant difference with I4, but, not only I3, but also I4 had significant differences with I1 and I2. The higher a thousand seed weight was obtained by I4 (34.85 g), followed by I3 (31.93 g), I2 (30.33 g), and I1 (28.76 g). I4 had significant difference with I1, but there was not any meaningful difference between I4 and I2 and I3. All differences among I1, I2 and I3 were not meaningful. The maximum and the minimum number of seed per spike was related to I3 (22.75) and I1 (17.98), which had significant difference with each other. The results from the study indicate that irrigation winter wheat throughout the booting stage and flowering stage increased grain yield, harvest index, potassium percentage, ash percentage of forage wheat at flowering stage, seed and forage protein percentage. Researchers reported that shortage of water resources has become the major limiting factor for wheat production [20,21,22] (Zhang et al., 2005; Sun et al., 2006; Zhao et al., 2007). Chaves et al. [23] conlcuded that the reaction of plants to water stress differ significantly, t various organizational levels, depending upon intensity and duration of stress as well as plant species and its stage of development. Han et al. [9] noted that better performance of crop depends on availability of irrigation water, especially at various growth stages. They also found that non-availability of water at early stage of crop grwoth showed reduction both in yield and yield quality of crops. Zhong-hu and Rajaram [24] found that the most sensitive wheat stage to drought was the kernel filling period. The grain weight remains fixed at pre-anthesis stage. Grain yield of wheat under hot and dry conditions is frequently limited by both high temperature and drought during grain growth. Halt irrigation induces a series of morphological and physiological changes in wheat such as a reduction in yield, kernel weight and leaf area index. Because of the need for water during fall and winter for winter wheat, irrigation should be done. In 2013-2014, the highest spike number per lysimeter was related to full irrigation (I4), but it had no significant differences with other treatments (P>0.05). I4 had obtained the highest grain yield which was 7.55 ton/ha. I4 had no meaningful differences with I3 (P>0.05), but both I3 and I4 had significant differences with I1 and I2 (P<0.05). Grain yield in I1 and I2 was 4.49 ton/ha and 4.65 ton/ha, respectively. The maximum and the minimum harvest index was related to I4 (44.79%) and I2 (37.97%), which had significant differences with each other (P<0.05). Harvest index in I3 was 42.84%. When producers have control over when they can irrigate, limiting water during the growth stages that are least sensitive to water stress while saving water for the critical growth stages is important to maximize return.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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