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IMPACT OF DIFFERENT IRRIGATION MANAGEMENTS ON SOIL WATER CONSUMPTION, GRAIN YIELD, SEED PROTEIN, PHOSPHORUS AND POTASSIUM OF WINTER WHEAT

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ABSTRACT. To evaluate soil water consumption, changes in quantity and quality of winter wheat seed and forage under different irrigation treatments, an experiment was conducted in Beijing, China, in the 2012-2013. Irrigation treatments were (I1): irrigation before sowing, (I2): irrigation before sowing + before freezing; (I3): irrigation before sowing + before freezing + irrigation in the beginning of erecting stage + irrigation at flowering stage; (I4): irrigation before sowing + irrigation before freezing + irrigation at the booting stage + irrigation at flowering stage. The laid out of experiment was randomized complete block design, repeated six times. The effect of irrigation on total biological yield, grain yield and harvest index is significant. The highest mean soil water consumption in Oct., Nov., Dec., Jan., Feb., Mar., Apr. and May was obtained for lysimeter 10 (I2), lysimeter 10 (I2), lysimeter 6 (I2), lysimeter 10 (I2), lysimeter 10 (I2), lysimeter 10 (I2), lysimeter 11 (I3), and lysimeter 10 (I2), respectively. 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. Evapotranspiration trends increased steadily, especially in last three months, in which the lysimeter fields were covered by winter wheat completely.

Keywords: weighing lysimeter; irrigation; soil water consumption; wheat; quality.

INTRODUCTION

Drought constitutes one of the major environmental limitations to crop productivity (Soleymani &

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Shahrajabian, 2012; Shahrajabian *et al.,* 2013). Soleymani *et al*. (2011) reported that the nutritional value of wheat is extremely important, as it takes an important place among the few crop species, being extensively grown as staple food sources. Weighing lysimeters have a long history of development and different designs have been used, moreover agronomic applications of weighing lysimeters have been numerous (Green *et al.,* 2013). Weighing lysimeters are the most accurate and direct method, but they are both expensive and immobile, and some time poor representation of conditions outside the area (Unlu *et al.,* 2010; Shahrajabian *et al.,* 2017). The scope for further irrigation development to meet food requirements in the coming years is, however, severely constrained by decreasing water resources. Amir *et al.* (2004) reported that protein content of wheat depends not only climatic factors, also on the fertilization, the nature of the soil and the amounts of water received during the filling and the maturation of the grains.

The objectives of this research were to study seed yield and quality of winter wheat forage and seed qualitative characteristics, and soil water consumption trends in each season for each lysimeter in Xiaotangshang, Beijing, China.

MATERIALS AND METHODS

The weighing lysimeter system is located in National Precision Agriculture Demonstration Station in Xiaotangshang Town of Beijing (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}. Irrigation treatments were (I1) (lysimeters 1, 5, 9, 13, 17 and 21): irrigation before sowing (60 L), (I2) (lysimeters 2, 6, 10, 14, 18, and 22): Irrigation before sowing (30 L) + before freezing (30 L); (I3) (lysimeters 3, 7, 11, 15, 19, and 23): irrigation before sowing (30 L) + before freezing (30 L) + irrigation in the beginning of erecting stage (60 L) + irrigation at flowering stage (60 L); (I4) (lysimeters 4, 8, 12, 16, and 24): irrigation before sowing (30 L) + irrigation before freezing (30 L) + irrigation at the booting stage (60 L) + irrigation at flowering stage (60 L). The laid out of experiment was randomized complete block design, repeated six times. 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 10th Oct. in 2012. A number of 500 seeds per each lysimeter were used in each lysimeter. For small lysimeter, to supply N, P and K, 337 g urea per each lysimeter, 337 g diammonium phosphate per each lysimeter, and 202 g K_2O per each lysimeter was used, respectively; 26.68 g zinc 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 1 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. 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 kg per ha. 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^{o}C for 4 h. Phosphorus percentage and potassium percentage were calculated by Olsen method and potassium dichromate volumetric methods. Analysis of variance (ANOVA) was used to determine the significant differences. Duncan's multiple range test was used for the separation of means. All statistics was performed with SAS program (p=0.05), and Excel program was used to illustrate and compare data on figures.

RESULTS AND DISCUSSION

The effect of irrigation on total biological yield, grain yield and harvest index is significant. However, phosphorous percentage, potassium percentage, ash percentage and protein percentage of forage wheat at flowering stage, seed phosphorus, seed potassium and seed protein percentage were not meaningfully affected by irrigation treatment (*Table 1*). The higher total biological yield was related to I3 (19.35 t/ha) than those of other treatments. I3 had meaningful differences with I1 and I2, but its difference with I4 was not significant. The lowest total biological yield was achieved in I4 (16.29 t/ha). A common adverse effect of water stress on crop plants is the reduction dry biomass production (Farooq *et al.,* 2009). The maximum and the minimum grain yield was obtained for I4 (4.87 t/ha) and I1 (2.87 t/ha), respectively. There were not any significant differences between I1 and I2, and I3 and I4, but both I3 and I4 had significant differences with I1 and I2. Water deficiency during the critical period results in poor growth and low yield. The highest harvest index was achieved in I4 (31.92%), followed by I3 (26.91%), I2 (25.14%), and I1 (20.58%). I1 had no significant difference with I2 and I3, but its difference with I4 was meaningful. The highest phosphorus percentage of winter wheat as a forage at flowering stage was I2 (0.26%), which had no significant differences with other irrigation treatments. I4 had obtained the maximum potassium percentage, and its difference with other treatments were 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 (*Fig. 1*). Li *et al.* (2003) demonstrated that the yield and quality of wheat is responded to the limited water supply, where the annual precipitation is not sufficient for the crop water requirement. 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 differences were found among I2, I3 and I4. Seed protein percentage in I2, I3 and I4 was 17.49%, 17.03% and 17.69% (*Fig. 1*) (*Table 2*). 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 1*). This result in agreement with Sohrabi *et al.* (2010), who stated that applying irrigation at end stages of plant growth caused a decrease in grain protein content. Wang *et al.* (2008) also observed that grain yield under irrigation treatments were significantly increased, but the content of grain protein was reduced in wheat.

Soil water consumption in lysimeter 1 (I1), 2 (I2), 3 (I3) and 4 (I4) in Oct was 481.71, 364.55, 384.15, and 432.49 kg. In November, the soil water consumption for lysimeter 1 (I1), 2 (I2), 3 (I3) and 4 (I4) was 501.85, 391.66, 409.96 and 465.71 kg. Soil water consumption in March for lysimeters 1 (I1), 2 (I2), 3 (I3) and 4 (I4) was 510.79, 401.63, 418.88 and 482.88 kg. In April, the numbers were 411.82, 301.67, 342.13 and 410.12 kg. In May, the numbers were 443.03, 336.57, 359.86 and 435.47 kg, respectively. In October, soil water consumption for lysimeters 5 (I1), 6 (I2), 7 (I3) and 8 (I4) was 438.37, 479.98, 467.92 and 496.76 kg. In November, these amounts were 454.69, 508.48, 477.41, and 510.02 kg. In December, these numbers were 471.02, 536.97, 486.89 and 523.27 kg. This amount in April was 358.82, 435.00, 434.45, and 458.50 kg. In January, soil water consumption was 513.45, 479.71, 508.14, and 502.94 kg. Lysimeters' soil water consumption was 527.28, 492.44, 504.44, and 500.27 kg, respectively, in February. Soil water consumption numbers for March was 521.90, 482.37, 495.92 and 492.59, and those data for April was 421.12, 372.28, 416.52 and 405.05 kg, respectively. Soil water consumption for lysimeters 13 (I1), 14 (I2), 15 (I3) and 16 (I4) was 447.12, 399.32, 420.89, and 409.59 kg, respectively, in May (*Fig. 1*). Abdou & Flury (2004) reported the importance of lysimeters, which are considered to be an intermediate approach between field studies and small-scale laboratory experiments.

Soil water consumption for lysimeters 17 (I1), 18 (I2), 19 (I3) and 20 (I4) was 480.50, 451.61, 461.87 and 468.49, respectively, in October. In November, these numbers were 498.70, 481.90, 488.95 and 497.72 kg. These numbers in December were 516.90, 512.19, 516.02 and 526.94 kg.

Table 1 - Mean comparison for experimental characteristics

Irrigation levels	Treatment					
	Total biological yield (t/ha)	Grain yield (t/ha)	Harvest index (%)	Seed phosphorus (%)	Seed potassium (%)	Seed protein (%)
I1	14.51b	2.87b	20.58b	0.38a	0.56a	18.16a
I2	13.11b	2.98b	25.14ab	0.40a	0.58a	17.49a
I3	19.35a	4.84a	26.91ab	0.42a	0.62a	17.03a
I4	16.29ab	4.87a	31.92a	0.41a	0.61a	17.69a

Common letter within each column do not differ significantly.
Irrigation treatments are = (I1): irrigation before sowing (60 L), (I2): irrigation before sowing (30 L) + before freezing (30 L); (I3): irrigation before sowing (30 L) + before freezing (30 L) + irrigation in the beginning of erecting stage (60 L) + irrigation at flowering stage (60 L); (I4): irrigation before sowing (30 L) + irrigation before freezing (30 L) + irrigation at the booting stage (60 L) + irrigation at flowering stage (60 L).

Table 2 - Mean comparison for experimental characteristics

Irrigation levels	Treatment			
	P (%) of forage wheat at flowering stage	K (%) of forage wheat at flowering stage	Ash (%) of forage wheat at flowering stage	Protein (%) of forage wheat at flowering stage
I1	0.24a	1.61a	5.39a	9.78a
I2	0.26a	1.43a	4.67a	9.99a
I3	0.24a	1.54a	5.06a	10.11a
I4	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 L), (I2): irrigation before sowing (30 L) + before freezing (30 L); (I3): irrigation before sowing (30 L) + before freezing (30 L) + irrigation in the beginning of erecting stage (60 L) + irrigation at flowering stage (60 L); (I4): irrigation before sowing (30 L) + irrigation before freezing (30 L) + irrigation at the booting stage (60 L) + irrigation at flowering stage (60 L).

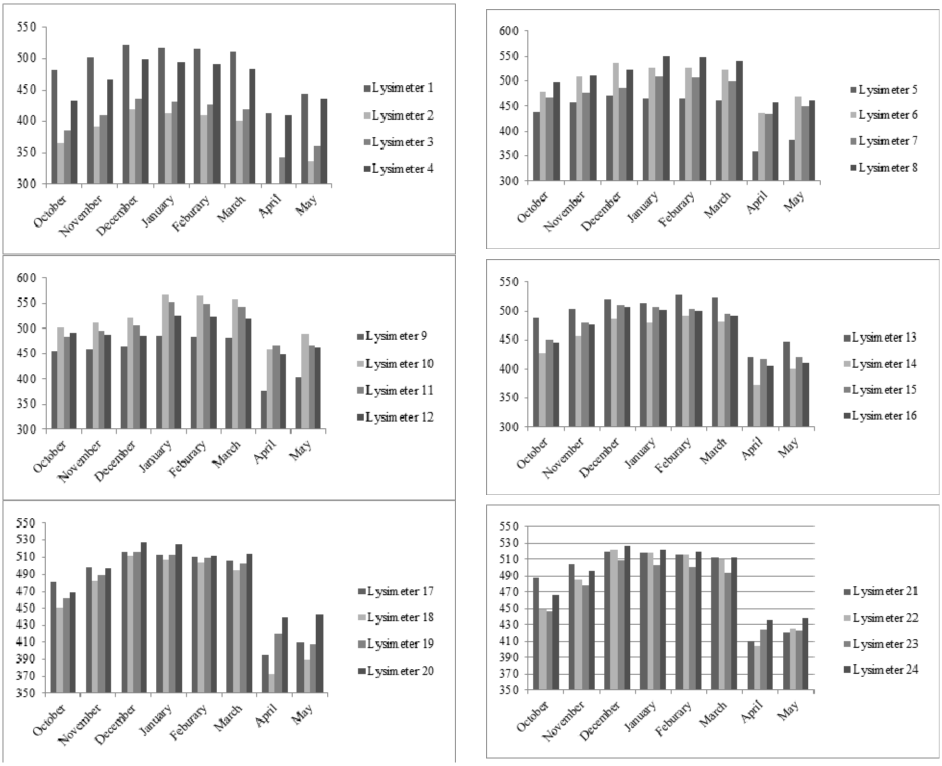

Figure 1 - Soil water consumption trend (kg) in different lysimeters

In January, soil water consumption for lysimeters 17 (I1), 18 (I2), 19 (I3) and 20 (I4) was 512.58, 506.44, 513.27 and 524.73 kg, respectively. These numbers in February were 510.85, 503.77, 509.66, and 512.13 kg, respectively. Soil water consumption for mentioned lysimeters in March was 506.08, 495.70, 501.71, and 513.99 kg, respectively, and for April, the numbers were 395.41, 372.35, 419.62 and 439.23 kg, respectively. In October, soil water consumption for lysimeters 21 (I1), 22 (I2), 23 (I3) and 24 (I4) was 487.79, 449.83, 447.42 and 466.73 kg, respectively. These numbers in November were 503.93, 485.98, 477.92 and 496.73 kg, and for December were 520.08, 522.13, 508.42, and 526.73 kg. In March, soil water consumption amounts for those mentioned lysimeters were 512.79, 509.56, 493.73 and 512.67 kg, respectively. In April, these numbers were 410.13, 404.25, 423.93 and 435.81 kg. Soil water consumption for May was 420.35, 424.77, 423.12 and 438.77 kg, respectively. Soil water content is the main limiting factor to growth and productivity of plants in dry areas (Singh & Singh, 2009).

Accumulative evapotranspiration trends for smal lysimeters in different months were measured. *Figs. 2 and 3* represent evapotranspiration in May and June in 2013, respectively. In these figures, evapotranspiration trends increased steadily, especially in last two months, in which the lysimeter were covered by winter wheat. Dynamic of evapotranspiration was shown in *Fig. 4*. Growth characteristics and the environmental conditions of crop influence on evapotranspiration and also with the progress in plant growth, water consumption changes.

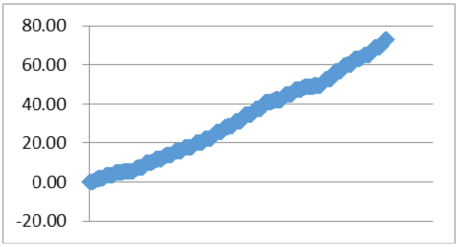

Figure 2 - Evapotranspiration in May 2013

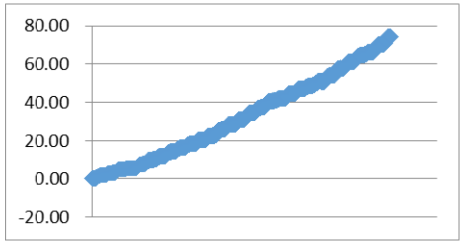

Figure 3 - Evapotranspiration in June 2013

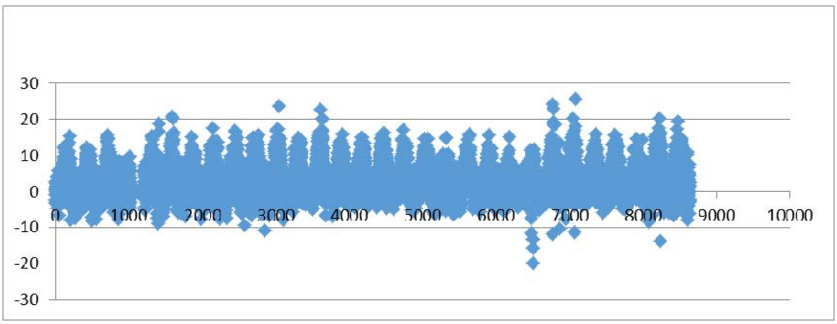

Figure 4 - Dynamic of evapotranspiration in May 2013

CONCLUSION

The availability of water plays an important role in plant growth, yield and quality of crops. As the world's population increases, water resources for agriculture become more restrictive and efficient water us takes on greater importance. The highest grain yield, harvest index, potassium percentage and ash percentage of forage wheat at flowering stage was obtained by I4 (irrigation before sowing (30 L) + irrigation before freezing (30 L) + irrigation at the booting stage (60 L) + irrigation at flowering stage (60 L). A significant increase in wheat yield may be achieved through improved irrigation management. The maximum total biological yield, forage protein percentage, seed phosphorus percentage and seed potassium percentage was related to I3 (irrigation before sowing (30 L) + before freezing (30 L) + irrigation in the beginning of erecting stage (60 L) + irrigation at flowering stage (60 L), but it had no significant differences with I4. With the increases of irrigation amount and frequency, the dry matter accumulated in vegetative organs before anthesis is distributed to grain in smaller amount and lower rate, and its contribution to grain yield is decreased. The highest mean soil water consumption in Oct., Nov., Dec., Jan., Feb., Mar., April and May was obtained for lysimeter 10 (I2) (502.0443 kg), lysimeter 10 (I2) (512.2649 kg), lysimeter 6 (I2) (536.9783 kg), lysimeter 10 (I2) (566.9811 kg), lysimeter 10 (I2) (564.8478 kg), lysimeter 10 (I2) (558.7015 kg), lysimeter 11 (I3) (301.6719 kg), and lysimeter 10 (I2) (488.68 kg), respectively.

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. Therefore, it can be concluded that it is important to irrigate winter wheat throughout the booting stage and flowering stage in order to achieve higher yield.

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