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Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorpjn@gmail.com

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Assessing Yield, Water Use Efficiency and Evapotranspiration with Ameliorating Effect of Potassium in Wheat Crop Exposed to Regulated Deficit Irrigation

Muhammad Imran[1], Anwar-Ul-Hassan[1], Muhammad Iqbal[1] and Ehsan Ullah[2]
[1]Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan
[2]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

Abstract: Water is the most important factor for plant growth while potassium fertilization plays an important role under deficit irrigation or under stress condition. A pot experiment was conducted to assess the yield and water use efficiency with amelioration effect of potassium in wheat crop exposed to regulated deficit irrigation. Wheat crop was sown for two years. Pot experiment was laid out following CRD with two factorial arrangements. Each treatment was replicated thrice. Wheat variety "Sahar-2006" was sown. All the measures were taken to control weeds, other pests and diseases for the crop management. Soil water content was measured by weighing pot after 1 to 2 day's interval throughout the growing season. Potential evapotranspiration was calculated using Penman-Montieth model. The ETa was calculated using water balance equation and crop coefficient was calculated from the lysimeter/pot trials. The data obtained was analyzed statistically. The result of this study showed that the maximum grain yield was observed with T_1 (HHHHH) at K_2 and second best was the T_2 (MMMMM: 70-80% FC at all stages) at K_2 because it showed minimum reduction in yield and save upto 20-30% water. It also showed the highest water use efficiency (WUE). It was also observed that the soil evaporation decreased with regulated deficit irrigation to some extent but it mostly depend upon on the hydraulic properties of soil. The treatment combination T3 (LLLLL: 60-70% FC at all growth satges) at K_2 showed the highest root mass density and root length density during 2010-11 and 2011-12, respectively. Regulated deficit irrigation (RDI) and potassium application have significant effect on crop coefficient (Kc) during 2010-11 and 2011-12 in Winter seasons.

Key words: Water use efficiency, actual evapotranspiration, crop coefficient, root length density, root mass density

INTRODUCTION

In Pakistan's economy, agriculture sector plays a central role. Its share in GDP is 21 and 45% of the country's total labour force is engaged in this sector. Now a day's, this sector is facing some emerging challenges such as water shortage and climatic changes (Anonymous, 2010-11). Wheat (*Triticum aestivum* L.) is the most important and most widely grown cereal crop and is also the staple food of the country. It contributes 13.1% to the value added in agriculture and 2.7% in GDP. There are many factors responsible for low yield of wheat in Pakistan but soil moisture is the most important. Soil water is one of the most important factors which influence yield and quality of crops. Crop water productivity of wheat (0.6-1.7 kg/m^3) is very low globally, which is even adverse in Pakistan, consequently it offers incredible opportunities for increasing or at least maintaining production of wheat crops with a less amount of water (Zwart and Bastiaanssen, 2004). Water is a basic necessity for life and is fast becoming an economically scarce resource in many areas of the world especially in arid and semiarid regions. In plants, functions of water are manifold, such as maintenance of turgidity, uptake and translocation of nutrients and metabolites, sequestration of excessive salts and toxic material into vacuoles or out of tissue and serving as medium for all biochemical and bio-energy reactions (Salisbury and Ross, 2005). However, Pakistan will face severe water shortage in future which ultimately will enhance food shortage. It is reported that the Pakistan will have approximately 32% less water during 2025 as compared to present situation which will produced 70 m ton food shortage. It is estimated that surface water storage capacity will be reduced by 30% during 2025 due to climatic changes and siltation of main reservoirs. The per capita water storage capacity in Pakistan is only 150 m^3 as compared to 5000 m^3 in US and Australia and 2200 m^3 in China (Qureshi, 2011). In Pakistan, there are many plans to overcome problems of food security. If anything, there will be less water than before as nonagricultural uses grow and compete for irrigation water. On the other hand melting of the glaciers gives tangible meaning to climatic change (Archer *et al*., 2010). The horrible impact of climatic change is drought. Approximately, sixty one percent of countries of the world receive less than 500 mm rainfall annually and wheat

Corresponding Author: Muhammad Imran, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan

crop is mostly cultivated in these semiarid regions (Deng *et al.*, 2004; El-Abady *et al.*, 2009). In order to combat with water shortage problem, the irrigation system will be changed towards maximizing the production per unit of water consumed rather than emphasizing on production per unit area (Fereres and Soriano, 2007). Therefore, techniques are needed to increase water use efficiency. The scarcity of water and high irrigation costs are forcing to established new methods of irrigation that increased water use efficiency and save the water for raising other crops (Tariq and Usman, 2009). There has been a wide range of proposed novel approaches to irrigation scheduling which have not yet been adopted. The regulated deficit irrigation (RDI) is one way of maximizing the water use efficiency for maximum yields per unit application of water (English and Raja, 1996). The decrease in yield will be nonsignificant as compared with benefit achieved through diverting the saved water (Eck *et al.*, 1987). The correct application of RDI requires thorough understanding of the yield response to water and of the economic impact of reductions in harvest. The saved water can be used to irrigate extra units of land. Water deficit plays a very important role in inhibiting the yields of crops. However, water shortage and its wastage now are the two inconsistency aspects in the usage of water resources worldwide (Ogola *et al.*, 2002). Thus in order to optimize crop yields and water use efficiency (WUE) in irrigated environments, irrigations should be timed in a way that non-productive soil water evapotranspiration and drainage losses are minimized and possible inevitable water deficits coincide with least sensitive growth period (Arora and Gajri, 1998). Wheat grown under the RDI schemes produced 17 and 29% more grain yield during 2003 and 2004, respectively as compared to control (Zhang *et al.*, 2005). Similarly, Chennafi *et al.* (2006) reported that yield and other wheat traits respond to applied water and the response was dependent on seasons, levels of regulated deficit irrigation and crop growth stage at which water was applied. Grain yield was correlated linearly to water use efficiency and curvi-linearly to total water evapotranspired. They also reported that the limited irrigation applied at heading stage increased grain yield effectively and decreased the crop failure risk.

Mineral nutrients play an important role in increasing plant resistance to drought stress (Marschner, 1995). Under regulated deficit irrigation, potassium fertilization increase crop tolerance to water stress by utilizing the soil moisture more efficiently than in K deficient plants. The increase in the stress tolerance by K fertilization may be due to promotion of root growth associated with more nutrient and water uptake (Umar and Din, 2002) and through the reduction of transpirational water loss. It also maintain the osmotic and turgor of the cell and regulate the stomatal functioning under water stress condition (Kant and Kafkafi, 2002) which is reflected in improved crop yield under drought conditions (Egila *et al.*, 2001; Umar and Din, 2002). The effective diffusion coefficient of K^+ was increased with increasing the soil moisture content at the lower side of the optimal soil moisture, therefore increased K^+ uptake (Mackay and Barber, 1985). The rate of root elongation is a crucial parameter in the uptake of nutrients that are strongly adsorbed to the soil and their concentration in the soil solution is usually very low (Kafkafi, 1991).

The detail methods for estimating evapotranspiration and calculation of crop water requirements for different crops under different climates, as needed in water balance calculation, have been reviewed in detail (Allen *et al.*, 1998). Determination of actual crop evapotranspiration (ETc) during the growing season has a potential advantage to attain proper irrigation scheduling. Crop coefficient (Kc) is widely used to estimate crop water use and to schedule irrigations. The concept of Kc was introduced (Jensen, 1968) and further developed by the other researchers (Allen *et al.*, 1998). Values of Kc for most agricultural crops increase from a minimum value at planting until a maximum Kc is reached at about full canopy cover. The Kc tends to decline at a point after a full cover is reached in the crop season. ETo may be measured directly from a reference crop such as a perennial grass (Watson and Burnett, 1995) or computed from weather data using the Penman-Monteith (P-M) equation. The Penman-Monteith (P-M) equation is adopted and recommended by FAO-56 (Allen *et al.*, 1998; Asce-Ewri, 2005) and can be applied to a variety of vegetation conditions, including systems having varying leaf area and varying height. It is possible to standardize parameters in the P-M equation including aerodynamic resistance for application to grass reference ETo (Allen *et al.*, 1998; Asce-Ewri, 2005). Weighing lysimeters are employed to measure ETo and ETc directly by detecting changes in the weight of the soil/crop unit (Marek *et al.*, 2006).

Keeping in view the above fact, this study will be conducted to achieve the following objectives:

1: Assessing yield and WUE under regulated deficit irrigation at various levels of potassium that was K_0: 0, K_1: 200 and K_2: 300 kg/ha, respectively
2: To calculate the K_c value for wheat crop under pot condition
3: To find out the ET_a at different growth stages under pot condition

MATERIALS AND METHODS

The pot and field experiments were conducted at the experimental farm of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan (Latitude, 31°-26' N and 73°-06' E, 184 m ASL) during the winter seasons of 2010-11 and 2011-12. The climate of the study area is semi subtropical-arid with more than 70% of the annual rainfall occurring during June to September. The soil type of the experiment site is well-drained Hafizabad sandy clay loam, mixed, semi-active, Isohyperthermic Typic Calciargids. Lysimeter/Pot experiment was laid out in CRD having two factors with factorial arrangements. Each treatment was replicated thrice. Plastic pot having capacity of 9 kg soil was used as weighing lysimeter. Each pot has 25 and 11 cm height and radius. Local high yielding wheat varity Sahar-2006 was planted. The sowing time was November 20, 2010 and November 25, 2011. Urea was applied at the rate of 120 kg N/ha in two splits while phosphorus was applied at 85 kg/ha and potassium was applied according to treatment plane at the time of sowing. Locally manufactured digital balance was used for weighing. It has weighing capacity in range from 200-30000+5 g. Data was collected according to (Dwyer *et al.*, 1987). Treatments plan was given in Table 1. Based on soil water measurements from weighing Lysimeter/Pot, the Actual Evapotranspiration was calculated using water balance equation:

$$Et_a = (I+p)-\Delta S \quad (1)$$

where, ET_a is the actual evapotranspiration (mm), I (mm) is irrigation, P (mm) is rainfall and ΔS (mm) is change in root zone storage. There was no excess water losses below the root zone because irrigation was scheduled based on soil water content in the root zone. The irrigation amount was calculated to replace the water content depleted. The crop coefficient was calculated as follows:

$$K_C = \frac{ET_a}{ET_0} \quad (2)$$

Daily reference/potential evapotranspiration (ET_0) for a hypothetical crop was calculated using The Penman-Monteith FAO-56 Equation (Allen *et al.*, 1998) as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean} + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3)$$

where, ET_0 is the reference/potential evapotranspiration (mm/day), R_n the net radiation reaching the crop surface ($M/Jm^2/day$), G the soil heat flux density ($MJ/m^2/day$), γ is the psychometric constant (kPa/°C), T_{mean} the average daily air temperature measured at 2 m height (°C), u_2 the wind speed at 2 m height (m/s), e_s-e_a the saturation vapour pressure deficit (kPa), e_a the actual vapour pressure (kPa), e_s the saturation vapour pressure (kPa) and the slope of the vapour pressure curve (kPa/°C). Water-use efficiency is defined as follows (Hussain *et al.*, 1995):

$$WUE = \frac{GY}{ET_a} \quad (4)$$

where, WUE (kg/ha/mm) is the water use efficiency for grain yield, GY is the grain yield (kg/ha) and ET_a (mm) is the actual evapotranspiration. Water retention curve was measured for soil. Retention capacity of soil was measured by determining water contents at pre-defined matric potential (Dane and Hopmans, 2002) with the help of suction plates at the 0.3, 0.6, 1.0, 3.0 and 4.5 bar pressure and a linear regression equation was determined by taking In (h) versus In θ/θ_s to get water contents at permanent wilting point (θ_{WP}) and field capacity (θ_{FC}) of different soils (Williams *et al.*, 1983). The following linear regression equation was developed by taking In θ/θ_s versus In (h) to get θ_{WP}, θ_{FC}, θ_{AWC} etc:

$$\text{InP} = \text{InP}_e + b\ln(\frac{\theta}{\theta_s}) \quad (5)$$

where, P is the matric potential (kPa), "P_e" (intercept) is air entry value/bubbling pressure which is inversely related to "α" and "b" is the slope of In P vs In θ/θ_s of water retention curve. The data collected was statistically analyzed using ANOVA (analysis of variance) techniques according to CRD design. The means were compared by LSD (least significant difference) test at $p<0.05$ (Steel *et al.*, 1997).

RESULTS AND DISCUSSION

The pot experiment was conducted at the experimental farm of the institute of soil and environmental Sciences, University of Agriculture, Faisalabad, Pakistan during the Winter seasons of 2010-11 and 2011-12 to study the effect of regulated deficit irrigation and potassium on evapotranspiration, yield and water use efficiency of wheat. The results of this study are as under.

Yield and yield contributing parameters of wheat: The effect of RDI and potassium on biological yield was significant on both years during 2010-2011 and 2011-2012, while their interactive effect on biological yield of wheat was also significant during both years (Table 2). The maximum biological yield was recorded in treatment combination T_1 (HHHHH) (water applied at 80-100% FC at all growth stages) and K_2 (Potassium at 300 kg/ha) that was 28.6 and 29 g/pot during 2010-2011 and 2011-12, respectively. It was statistically at par with treatment combination T_1 at K_1 and T_1 at K_0 during 2010-11 while it was statistically different from T_1 at K_0 during 2011-12. These results are in line with Alderfasi and Refay (2010) who reported that gradual decrease in most growth parameters are in line with decreasing irrigation schedules. They also reported that the irrigation at 100 and 150 mm of CPE was statistically at par with regard

Table 1: Treatment plan used in experiment during 2010-11 and 2011-12

		Jointing*	Booting	Heading	Filling	Maturity
Potassium	Irrigation	LU	LU	LU	LU	LU
K_0: No potassium	T_1 (HHHHH)	80-100	80-100	80-100	80-100	80-100
	T_2 (MMMMM)	70-80	70-80	70-80	70-80	70-80
	T_3 (LLLLL)	60-70	60-70	60-70	60-70	60-70
K_1: Potassium at 200 kg/ha	T_1 (HHHHH)	80-100	80-100	80-100	80-100	80-100
	T_2 (MMMMM)	70-80	70-80	70-80	70-80	70-80
	T_3 (LLLLL)	60-70	60-70	60-70	60-70	60-70
K_2: Potassium at 300 kg/ha	T_1 (HHHHH)	80-100	80-100	80-100	80-100	80-100
	T_2 (MMMMM)	70- 80	70-80	70-80	70-80	70-80
	T_3 (LLLLL)	60-70	60-70	60-70	60-70	60-70

*S1: Germination stage (0-15DAS) S2: Jointing (15-45) S3: Booting (45-60)
S4: Heading (60-90) S5: Grain filling (90-112) S6: Maturity stage (112-140 DAS)

Table 2: Effect of RDI and Potassium on yield and yield contributing parameters of wheat under pot experiment during 2010-11 and 2011-12

	Grain yield (g/pot)			Biological yield (g/pot)			Harvest index (%)		
	K_0	K_1	K_2	K_0	K_1	K_2	K_0	K_1	K_2
Treatments	2010-11								
T_1 (HHHHH)	10.14	10.19	10.73	28.00	28.35	28.60	36.21	35.95	37.52
T_2 (MMMMM)	9.02	9.18	9.65	25.71	27.07	27.36	35.09	33.90	35.27
T_3 (LLLLL)	7.20	7.40	7.55	22.24	22.48	22.69	32.40	32.91	33.28
LSD (p<0.05)	0.27	-	-	0.72	-	-	0.08	-	-
	2011-12								
T_1 (HHHHH)	10.64	10.68	11.26	28.43	28.80	29.00	37.43	37.08	38.82
T_2 (MMMMM)	9.48	10.14	10.22	26.08	27.79	28.07	36.36	36.48	36.39
T_3 (LLLLL)	7.57	7.80	7.95	22.59	22.83	23.01	33.49	34.15	34.57
SD (p<0.05)	0.12	-	-	0.23	-	-	0.11	-	-

to growth characters and K rates influenced growth vigor mostly through leaf area and dry matter production. The maximum grain yield was recorded in treatment combination T_1 (HHHHH) (80-100% FC at all growth stages) and K_2 (Potassium at 300 kg/ha) that was 10.73 and 11.26 g/pot during 2010-2011 and 2011-12, respectively. It was statistically significant from all other treatment combinations during both years. The treatment combination T_1 at K_1 and T_1 at K_0 was statistically at par with each other during both years. Our results are supported by Kazemeini and Edalat (2011) who reported the highest grain yield (4333 kg/ha) with T_1 (100% FC in all growth stages) while minimum was recorded (1,377 kg/ha) with T_{13} (50% FC in all growth stages). Grain yield was decreased with decreasing amount of water. The maximum harvest index was recorded in treatment combination T_1 (HHHHH) (80-100% FC at all growth stages) and K_2 (Potassium at 300 kg/ha) that was 37.52 and 38.82% during 2010-11 and 2011-12, respectively. The second best treatment was T_2 (MMMMM) (70-80% FC at all growth stages) at K_2 which showed 35.27 and 36.39% during first and second year, respectively. Work of Zhang *et al.* (2006) supported the results of current study. They observed 23.5-27.3% improvement in harvest index of wheat grown under regulated deficit irrigation. Less harvest index was also observed with deficit irrigation at vegetative and reproductive stage that was 39% (Moghaddam *et al.*, 2012).

Crop coefficient (Kc) of wheat at six stages: Data presented in Table 3 showed that RDI and potassium had significant effect on crop coefficient (Kc) at jointing, booting, heading, grain filling and maturity stages (except germination/initial stage). At jointing stage, Kc ranged from 0.56-0.93 and 0.56-0.95, respectively during 2010-11 and 2011-12. At this stage, the maximum Kc was recorded in T_1 (HHHHH) at K_2 during 2010-11 and 2011-12. The Kc ranged from 1.07-1.18 and 1.09-1.20 at booting stage during first and second year. At heading stage highest Kc was observed because at this stage the vegetative growth reached at maximum level and Kc ranged 1.09-1.22 and 1.11-1.24, respectively during 2010-11 and 2011-12. The treatment T_2 at K_2 showed maximum Kc value during both years at heading. At grain filling stage, Kc value showed decline because crop tended toward maturity. The Kc value ranged from 0.70-1.03 and 0.71-1.1.05 at grain filling during both the years, respectively. At maturity, the Kc value ranged from 0.39-0.72 and 0.40-0.74, respectively during 2010-11 and 2011-12. During both years, the treatment T_1 (80-100% FC at all growth stages) at K_2 showed highest Kc value except heading stage where treatment T_3 (MMMMM) at K_2 showed maximum value of Kc. The higher value of Kc at heading in T2 with K_2 might be due to the availability of soil moisture because the moisture content of this treatment reached at minimum level that was 70% of FC (field capacity) and irrigation was applied to raise the moisture content at upper level of FC that was 80% of FC. Our results are supported by those of Doorenbos and Pruitt (1977) who divided the crop coefficient (K_c) curve into four stages: Initial, crop development, mid and end-season stages. Similarly, Li *et al.* (2003) calculated Kc values were 0.55, 1.03, 1.19 and 0.65 for the initial, crop development, mid-season and late-season stages, respectively. In other study, Kc

Table 3: Effect of RDI and Potassium on crop coefficient (Kc) of wheat at six stages under pot experiment during 2010-11 and 2011-12

	Stages																	
	K_o						K_1						K_2					
	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	S5	S6
Treatments	2010-11																	
T_1 (HHHHH)	0.56	0.9	1.12	1.13	1.01	0.71	0.57	0.91	1.15	1.17	1.02	0.72	0.58	0.93	1.18	1.18	1.03	0.73
T_2 (MMMMM)	0.56	0.57	1.11	1.13	0.9	0.61	0.57	0.58	1.14	1.17	0.91	0.62	0.58	0.59	1.17	1.22	0.92	0.63
T_3 (LLLLL)	0.55	0.56	1.07	1.09	0.7	0.39	0.56	0.57	1.08	1.1	0.71	0.4	0.57	0.58	1.09	1.11	0.72	0.41
LSD ($p\leq0.05$)	ns	0.01	0.01	0.011	0.011	0.01	-	-	-	-	-	-	-	-	-	-	-	-
	2011-12																	
T_1 (HHHHH)	0.57	0.92	1.14	1.15	1.03	0.72	0.58	0.93	1.17	1.19	1.04	0.73	0.59	0.95	1.2	1.2	1.05	0.74
T_2 (MMMMM)	0.57	0.58	1.13	1.15	0.92	0.62	0.58	0.59	1.16	1.19	0.93	0.63	0.59	0.6	1.19	1.24	0.94	0.64
T_3 (LLLLL)	0.56	0.57	1.09	1.11	0.71	0.40	0.57	0.58	1.1	1.12	0.72	0.41	0.58	0.59	1.11	1.13	0.73	0.42
LSD ($p\leq0.05$)	ns	0.02	0.01	0.01	0.01	0.01	-	-	-	-	-	-	-	-	-	-	-	-

S1: Germination stage S2: Jointing S3: Booting S4: Heading S5: Grain filling S6: Maturity stage

Table 4: Effect of RDI and Potassium on evapotranspiration (ETa) of wheat at six stages under pot experiment during 2010-11 and 2011-12 (mm)

	Stages																	
	K_o						K_1						K_2					
	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	S5	S6
Treatments	2010-11																	
T_1 (HHHHH)	13.4	33.7	18.1	64.1	48.4	89.7	13.7	34	18.6	66.3	48.9	91	13.9	34.8	19.1	66.9	49.3	92.3
T_2 (MMMMM)	13.4	21.3	18	64.1	43.1	77.1	13.7	21.7	18.5	66.3	43.6	78.4	13.9	22.1	19	69.2	44.1	79.6
T_3 (LLLLL)	13.2	20.9	17.3	61.8	33.5	49.3	13.4	21.3	17.5	62.4	34	50.6	13.7	21.7	17.7	62.9	34.5	51.8
LSD ($p\leq0.05$)	0.04	0.18	0.05	0.11	0.19	0.22	-	-	-	-	-	-	-	-	-	-	-	-
	2011-12																	
T_1 (HHHHH)	13	34	22.2	65.6	61.9	85.8	13.2	34.4	22.8	67.8	62.5	87	13.5	35.2	23.4	68.4	63.1	88.2
T_2 (MMMMM)	13	21.5	22	65.6	55.3	73.9	13.2	21.8	22.6	67.8	55.9	75.1	13.5	22.2	23.2	70.7	56.5	76.3
T_3 (LLLLL)	12.8	21.1	21.3	63.3	42.7	47.7	13	21.5	21.5	63.8	43.3	48.9	13.2	21.8	21.6	64.4	43.9	50.1
LSD ($p\leq0.05$)	0.01	0.18	0.06	0.11	0.25	0.21	-	-	-	-	-	-	-	-	-	-	-	-

values were determined over the growing seasons varied from 0.1 to 1.7 for wheat (Ko *et al*., 2009). They reported that the development of regionally based and growth-stage-specific Kc helps in irrigation management and provides precise water applications.

Evapotranspiration (ETa) of wheat: Data given in Table 4 revealed that RDI, potassium and their interaction have significant effect on ETa at jointing, booting, heading, grain filling and maturity stage except germination/ initial stage. The ETa ranged from 20.9-34.8 and 21.1-35.2 mm at jointing, 17.3-19.1 and 21.3-23.4 mm at booting, 61.8-69.2 and 63.3-70.7 mm at heading, 33.5-49.3 and 42.7-63.1 mm at grain filling and 49.3-92.3 and 47.7-88.2 mm at maturity stage, respectively during 2010-11 and 2011-12 in Winter seasons. In case of seasonal (Table 5), the ETa ranged 196.0-276.3 and 208.9-291.8 mm, respectively during 2010-11 and 2011-12 in winter seasons. The maximum Eta was observed in treatment T_1 (HHHHH) (80-100% FC at all growth stages) at K_2 during both years. It was followed in descending order by T_1 at K_1, K_0, T_2 (MMMMM) at K_2, K_1, K_0, T_3 (LLLLL) at K_2, K_1 and K_0 during 2010-11. During 2011-12, it was followed in descending order by T_1 at K_1, K_0, T_2 at K_2, K_1 and T_3 at K_2, K_1 and K_0. Evapotranspiration, an important aspect of water balance and a key factor to determine proper irrigation schedule and to improve water use efficiency in irrigated agriculture is successfully estimated by the crop coefficient- reference evapotranspirtion (K_c-ET_0) method. Our results are in line with Liu and Zhang (2002) who reported that total water consumption averaged 453 and 423 mm for Winter wheat without water deficit. Evaporation from the soil surface took up 29.7% of the total evapotranspiration for Winter wheat equaling an annual loss of more than 250 mm water. Thus, reducing soil evaporation could be one of the most important water-saving measures in this serious water deficit era.

Water use efficiency (WUE) kg/m^3: It was observed from the data presented in Table-6 that RDI, Potassium rate and their interaction have a significant effect on water use efficiency (WUE) of wheat crop. The treatment T_2 (MMMMM) at K_2 showed the maximum WUE of 1.02 Kg/ m^3 during 2010-11 and 2011-12. It was followed by T_1 at K_2 and T_3 with K_2 which showed 1.02, 0.98, 1.01 and 0.96 kg/m^3, respectively during first and second year. Our results are in conformity with those of Du *et al*. (2010) who reported that water deficit in any stage might improve WUE with slight reduction in grain yield of winter wheat. Water deficit at planting-stem elongation stage is the best choice for improved WUE and its increment also decreased with deficit irrigation treatments. Moreover, WUE under severe water deficit at seedling-stem elongation, stem elongation-booting and booting-milking reduced by 5.61, 9.25 and 10.07%, respectively, which implied that severe water deficit was not suitable at any stage. Mild water deficit at seedling-stem elongation and milking-harvesting stage decreased WUE by 3.22 and 3.64%, but it produced 21.5% more grain yield under mild water deficit at seedling-stem elongation than that under milking-harvesting stage (Karrou *et al*., 2012; Quanqi *et al*., 2010).

Table 5: Effect of RDI and Potassium on seasonal evapotranspiration (ETa) of wheat under pot experiment during 2011-12 and 2011-12 (mm)

	---------- 2010-11 ---------			------------ 2011-12 ------------		
Treatments	K_0	K_1	K_2	K_0	K_1	K_2
T_1 (HHHHH)	267.4	272.5	276.3	282.5	287.7	291.8
T_2 (MMMMM)	237.0	242.2	247.9	251.3	256.4	262.4
T_3 (LLLLL)	196.0	199.2	202.3	208.9	212.0	215.0
LSD ($p<0.05$)	0.55	-	-	0.59	-	-

Table 6: Effect of RDI and potassium on Water Use Efficiency (WUE) of wheat under pot experiment during 2010-11 and 2011-12 (kg/m)

	---------- 2010-11 ----------			----------- 2011-12 ----------		
Treatments	K_0	K_1	K_2	K_0	K_1	K_2
T_1 (HHHHH)	0.99	0.98	1.02	0.98	0.96	1.01
T_2 (MMMMM)	1.01	1.00	1.02	0.98	1.00	1.02
T_3 (LLLLL)	0.96	0.97	0.98	0.94	0.95	0.96
LSD ($p<0.05$)	0.021	-	-	0.01	-	-

Root mass (g/cm^3) and Length density (cm/cm^3): Root mass and length density of wheat was significantly affected by irrigation and potassium levels during 2010-11 and 2011-12 as given in Table 7. Root mass density was ranged from 0.81-1.07 and 0.85-1.12 g/cm^3, respectively, during first and second year. The treatment combination T3 (LLLLL) at K2 showed the highest root mass density. The treatment T_3 at K_2 followed in descending order by T_3 at K_1, T_2 (MMMMM) at K_1 and K_2, T_1 (HHHHH) at K_2, T_1 at K_1, T_3 at K_0, T_2 at K_0 and T_1 at K_0 during 2010-11. Similar trend was observed during 2011-12. Root length density ranged 2.32-3.05 and 2.43-3.20, respectively during 2010-11 and 2011-12. The treatment combination T3 (LLLLL) at K_2 showed the highest root length density that was 3.05 and 3.20 cm/cm^3, respectively during 2010-11 and 2011-12 while minimum was reported in treatment combination T_1 (HHHHH) at K_0 that was 2.32 and 2.43 cm/cm^3 during 2010-11 and 2011-12. It was followed in descending order by T_3 at K_1, T_2 (MMMMM) at K_1 and K_2, T_1 (HHHHH) at K_2 and K_1, T_3 at K_0, T_2 at K_0 and T_1 at K_0, respectively during both years. The increase in root mass and length density in treatment T_3 (LLLLL) might be due to regulated deficit irrigation because root growth was more under deficit irrigation to fulfil the evapotranspiration demand of crop. Our results are in agreement with Xue *et al*. (2003) who reported that irrigation significantly affected the rooting pattern. At booting, root length density in rain fed plot was higher than the irrigated plot. The irrigation during later part of winter wheat growing seasons and increase in irrigation

Table 7: Effect of RDI and Potassium on root mass density and root length density under lysimeter condition

	Root mass density (g/cm)			Root length density (cm/cm)		
Treatments	K_0	K_1	K_2	K_0	K_1	K_2
	2010-11					
T_1 (HHHHH)	0.81	0.98	1.01	2.32	2.80	2.84
T_2 (MMMMM)	0.87	1.02	1.01	2.48	2.90	2.89
T_3 (LLLLL)	0.95	1.05	1.07	2.72	2.99	3.05
LSD (p<0.05)	0.083	-	-	0.074	-	-
	2011-12					
T_1 (HHHHH)	0.85	1.03	1.05	2.43	2.94	2.99
T_2 (MMMMM)	0.91	1.07	1.06	2.60	3.05	3.03
T_3 (LLLLL)	1.02	1.10	1.12	2.86	3.14	3.20
LSD (p<0.05)	0.052	-	-	0.079	-	-

frequency decreased the available soil water due to change in vertical distribution of root length density. They also observed increase in root length density with 3 times irrigation at jointing, heading and milking stage in soil profile <30 cm depth. The highest root length density was observed in soil profile >30 cm depth with single irrigation at jointing stage (Quanqi *et al*., 2010). Previous studies also showed that soil drying at early stage stimulated root growth, particularly the root growth in the deeper soil profile (Zhang *et al*., 1998). The positive correlation of RWD and RLD with proper irrigation is evident from many studies (Sangakkara *et al*., 2010).

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