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Foliar application of potassium at different pheno-phases subjected to water deficit levels improved yield and yield attributes of wheat

Nawab Ali*[1], Amir Zaman Khan[1], Muhammad Mehran Anjum[1], Gul Roz Khan[1], Gul Daraz Khan[3], Haq Nawaz[1], Ibadullah[2], Salman Ali[1], Mehran Ali[1] and Sarmad Iqbal[1]

[1]Department of Agronomy, Faculty of Crop Production Sciences, The University of Agriculture Peshawar, **Pakistan**
[2]Department of Soil and Environmental Sciences, Faculty of Crop Production Sciences, The University of Agriculture Peshawar, **Pakistan**
[3]Department of Water Management, Faculty of Crop Production Sciences, The University of Agriculture Peshawar, **Pakistan**

***Correspondence:** nawab@aup.edu.pk **Received: 24-09-2019, Revised: 05-11-2019, Accepted: 11-11-2019 e-Published: 16-11-2019**

Water stress at critical growth stages diminishes the wheat production and has harmful effect on crop growth and development, however regulated water deficit and potassium foliar application ameliorates its adverse effect up to a certain extent. Screen house study was conducted in Complete Randomized Design (CRD) having four repeats. Varieties of wheat i.e. Lalma (drought resistant) and Pakhtunkhwa-2015 (drought susceptible), water stresses i.e. mild water stress (50 % of water required for field capacity) and severe stress (no application of water) at different growth stages of the crop and potassium (K) foliar spray (1%) including control (no stress + no spray) were the treatments. Results showed that application of potassium spray at three critical stages mitigated the adverse effects of both stress levels. Potassium foliar application at grain filling stage stress of the crop showed maximum increase in plant height (76.3 cm), spike length (10.1 cm), grains per spike (53), spikelet per spike (18), grains weight (3.87g), biomass yield (4.70 g plant^{-1}), grain yield (1.99 g plant^{-1}), harvest index (42 %) and water balance of the plants in terms of relative water contents (RWC) of the wheat crop. Among varieties Lalma has produced maximum grains spike^{-1} (54.2), hundred seeds weight (3.94 g), biomass yield (4.88 g plant^{-1}) and grain yield (2.01 g plant^{-1}) as compared to Pakhtunkhwa-2015. It is concluded that application of foliar potassium decreases the adverse effect of water stress at any growth stage, although grain filling stage was found more sensitive.

Keywords: Water Stress, K foliar application, growth stages, phenology, wheat yield

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops grown in all over the world including Pakistan (Hussain and Shah. 2002). Wheat is consumed as staple food by about one third of the world population because of its carbohydrate and nutritive value. Among the cereals, it ranks first in Pakistan and was cultivated on about 9.25 million ha area with total production of 25.5 million tons, while in Khyber Pakhtunkhwa province area under cultivation was 0.75 million ha with production about 1.4 million tons for the same year (MNFS and R, 2015). Population is increasing with an alarming rate and demand for wheat is also increasing correspondingly. To cope with this situation and overcome food insecurity more area should be brought under cultivation for increasing production. It is used as a staple food for urban and rural societies and as a major source of straw for animal feeding. Besides this, optimum yield could also be achieved through selection of recently developed high yielding, resistant to diseases and lodging varieties, proper amount and time of irrigation and provision of proper nutrition and their method of application.

Water stress is the most important stress among abiotic stresses which adversely suppress crop growth, development as well as production in the globe (Shahbaz *et al*., 2011). Slow germination and poor growth of seedlings is resulted through exposure to drought stress (Ashraf et al., 2006), plant development is affected (Xu et al., 2007) and ultimately cause reduction in harvestable yield of various crops (Nawaz *et al.,* 2012). Water deficit, when crop is at grain filling stage of development could be limiting the filling rate and as well as their processes which as consequences of the aforesaid stress resulting in small size of the grain, commencement of earlier physiological maturity, reduction in grains number, minimum weight of grain and ultimately wheat yield (Gupta et al., 2001). Likewise, lower growth and yield were observed by increasing drought stress in wheat crop (Jamieson et al., 1995).

Potassium (K) is abundant among cations found in plants, have a key role in various processes of plant physiology such as photosynthesis, assimilate transport and enzyme activation. It is one of the essential nutrients for optimum production and can be a limiting factor for various crops under varying environmental circumstances, for example drought (Liebersbach et al., 2004) for optimum plant growth (Rashid et al., 1998). Potassium improves the resistance and tolerance to various environmental stresses when used as foliar spray under drought condition. It also improved subsequent growth and yield of the crop plants. It also plays a key role in osmoregulation, photosynthesis, transpiration, stomatal conductance and protein formation etc. (Cakmak, 2005; Milford and Johnston, 2007). Hermans et al., 2006 reported that reduction in crop growth when there is no optimum supply of K to crop. Plant tolerance to drought is enhanced by the processes to apply K which have a key role in decreasing the detrimental effect of drought stress of soil (Marchner, 1995; Reddya et al., 2004).

Keeping in view the importance of potassium foliar application under water deficit at different stages of the crop growth, this experiment was designed to examine the study of foliar potassium applied on growth and yield of wheat under different moisture stress.

MATERIALS AND METHODS

Site and experiment

Experiment was conducted in Screen house, Department of Plant Breeding and Genetics, The University of Agriculture, Peshawar during Rabi crop season 2016-17. Experimental site was located 359 m above sea level. The climatic conditions of research site are semi-arid, subtropical with annual rainfall of less than 360 mm. Soil pH varies from 7.5 to 7.8, silty clay loam soil textural class and deficient in total N (>0.5 g kg-1). The experiment was conducted in pots under Complete Randomized Design (CRD) replicated four times. Each pot (27cm height and 22 in diameter) was filled from 8 kg of soil. About 10 seeds in each pot of two varieties Lalma (drought resistant) and Pakhtunkhwa-2015 (drought susceptible) were sown whereas water stresses i.e. mild water stress (50 % of the field capacity) and severe stress (no application of water) at different growth stages of the crop and Potassium (K) foliar spray (1%) in combinations which comprised of control (no stress + no spray), mild stress at tillering + K spray (1%), mild stress at flowering + K spray (1%), mild stress at grain filling + K Spray (1%), severe stress at tillering + K Spray (1%), severe stress at flowering + K spray (1%), severe stress at grain filling + K spray (1%), mild stress at tillering + no spray, mild stress at flowering + no spray, mild stress at grain filling + no spray, severe stress at tillering + no spray, severe stress at flowering + no spray and severe stress at grain filling + no spray. Gypsum blocks were calibrated (Fig. 1) before starting the experiment which were also installed in pots for maintaining water stress by measuring and maintaining of soil moisture through soil moisture meter (Model 5910A). Mild water stress (50 % of water required for field capacity) and severe water stress (no application of water) was maintained at three different stages of crop growth. After that Potassium (K) foliar spray 1 % was applied in combination with carboxymethyl cellulose (5% solution) for sticking and Tween-20 (0.1% solution) as a surfactant. Potassium sulfate (K_2SO_4) was used as source of Potassium, which was sprayed on the crop under water stress at three critical growth stages like GS 22, GS 60 and GS 73 (Zadoks) i.e. tillering, flower initiation and grain filling stages. All other agronomic practices like weeds, insect and pest control etc. were uniform for all treatments.

MEASUREMENT AND OBSERVATIONS

Number of days to anthesis and physiological maturity were counted from date of sowing till commencement of anthesis and maturity of the crop respectively in each treatment. Plant height was measured through meter rod. Spike length (cm) was measured at maturity of all 4 plants in pot and then averaged. Grains spike^{-1} were measured in each pot by threshing manually, counted and averaged. Hundred grains weight was measured by weighing about hundred grains of each treatment with the help of sensitive electronic balance. Biomass (g plant^{-1}) and grain yield (g plant^{-1}) of all the 4 plants was measured after harvesting, sun drying and threshing respectively through balance. For determining relative water content (RWC) second leaf of plants was taken from each pot. Fresh weight (FW) immediately recorded, and then leaves were soaked for 4 hours in distilled water at room temperature under a constant light and turgid weight (TW) was recorded followed by drying for 24 hours at 80 ºC for dry weights (DW).

$$RWC = \{(FW – DW) / (TW – DW)\} \times 100$$

Data significance were studied by analysis of variance (ANOVA) as the procedure referred by Steel et al. (1997) and treatment means, found significant, were compared using least significant difference (LSD) test ($p \leq 0.05$).

RESULTS

Phenology and growth

Days to emergence were non-significant for both the varieties (data not shown). However, days to anthesis were significantly ($p \leq 0.05$) influenced by water stress levels at tillering stage, Potassium foliar application and wheat varieties (Table 1). Planned mean comparison of control vs rest was also found significant while interactions were non-significant. Maximum days to anthesis were recorded for Lalma as compared to Pakhtunkhwa-2015. Among the different water stress levels, maximum days to anthesis were noticed when mild water stress was applied at tillering stage as compared to severe water stress. The maximum days to anthesis were recorded for Potassium foliar spray @ 1 % while minimum days were taken to anthesis were observed where no potassium spray was applied. Likewise, maximum days to anthesis in control treatments were noticed compared to rest treatments. This may be due to the water stress occurred at tillering and flowering stage, hence the plant starts anthesis earlier. In varieties, the reason for maximum and minimum days to anthesis could be genetic makeup of the varieties. Similar results have also been reported by Hafid et al. (1996). These results agree with those reported by Saleem (2007) and Mohamed (2013) who reported that increasing drought stress decreased days to anthesis. Potassium foliar application delayed days to anthesis, reason might be the role of potassium as stress tolerant and maintenance of plant physiological and biochemical processes under stress conditions.

Plant height (cm) of wheat crop as influenced by application of potassium as foliar under water stress are given in fig 1. Water stress, stress application stages, Potassium foliar spray and varieties significantly ($p \leq 0.05$) affected plant height of wheat crop.The planned mean comparison of control vs rest was also significant. Maximum plant height was measured for Lalma as compared to Pakhtunkhwa-2015. Likewise, maximum plant height was noticed when stress was imposed at grain filling stage followed by stress application at tillering stage while minimum plant height was obtained when stress was imposed at flowering stage. Similarly, maximum and minimum plant height was recorded for mild and severe stress respectively. Potassium foliar application resulted in maximum plant height when compared with no spray. Interactions of V x K (Fig. 2) and V x STR (Fig. 3) has significant influence on plant height of wheat.

Plant height of variety Lalma was increased through foliar potassium application while it has no effect on plant height of Pakhtunkhwa-2015. The reason for maximum and minimum plant height could be genetic make-up of the varieties. Comparable results have also been described by Hafid et al., (1996). Decrease in plant height was noticed under water stress imposition; similar result was attained by Khan et al., (2001).Water stress imposition, whichever at vegetative or at flowering phase condensed the plant height, however relatively more adversative influence was observed at flowering stage. Due to the dehydration in protoplasm plant height is decreased; relative turgidity is also decreased and hence it is associated with loss of turgor and ultimately reduced cell development and division of cell (Hussain et al., 2008).

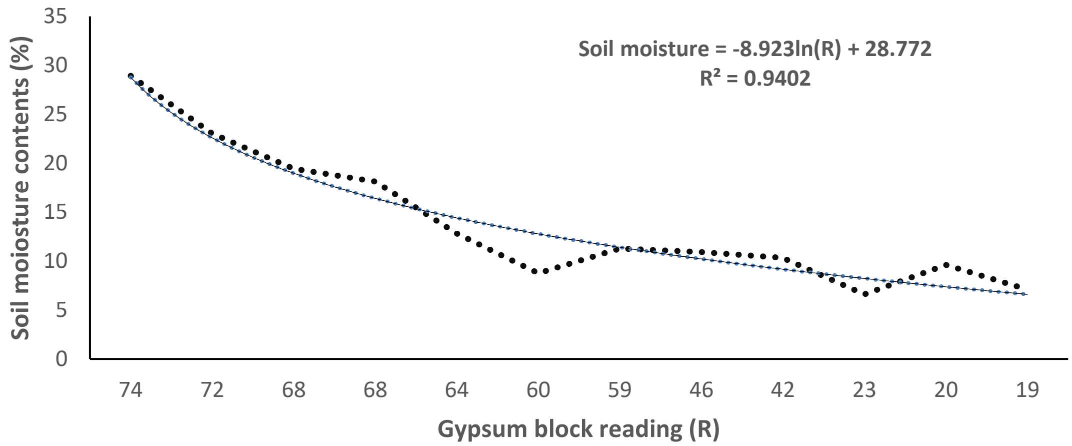

Figure 1;Gypsum block calibration done before starting of the experiment showing soil moisture contents (%) curve against moisture meter readings

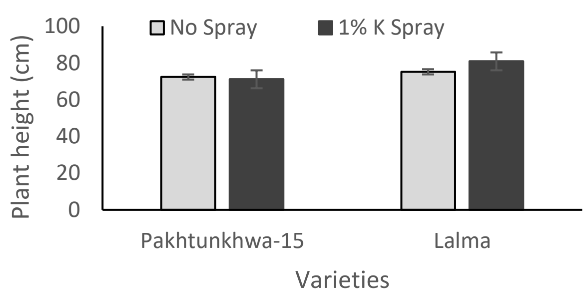

Figure 2; Interaction of V x K for plant height (cm) of wheat crop.

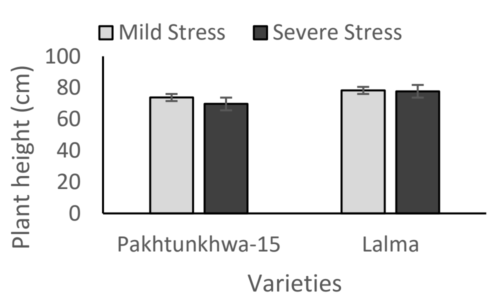

Figure. 3. Interaction of V x STR for plant height (cm) of wheat crop.

Table 1; Days to anthesis (DTA), plant height (PH), days to physiological maturity (DTM), grain per spike (GPS), hundred seed weight (HSW), grain yield (GY), biological yield (BY) and relative water contents (RWC) of wheat varieties as influenced by potassium foliar application under water stress

Varieties	DTA	PH (cm)	DTM	SL (cm)	GPS	HSW (g)	GY (g plant^{-1})	BY (g plant^{-1})	RWC (%)
Pakhtunkhwa -2015	110	72.3	157	9	52.1	3.73	4.58	1.91	67.8
Lalma	107	82.7	155	11.4	54.2	3.94	4.88	2.1	67.6
Stress application stages (ST)									
Tillering	-	74.5	155.6 a	9.7	52.3 b	3.58 c	4.55 b	1.89 b	66.5 a
Flowering	-	73.8	147.8 ab	9.6	51.9 b	3.72 b	4.57 b	1.76 c	62 b
Grain filling	-	76.3	153.8 a	10.1	53.1 a	3.87 a	4.7 a	1.99 a	58.8 c
LSD (0.05)		1.9	1.7	0.4	0.9	0.1	0.1	0.05	3
Water stress (STR)									
Mild	111	76.0	153.5	10	53.5	3.8	4.62	1.92	66
Severe	106	73.7	151.3	9.6	51.3	3.65	4.57	1.84	58.9
Potassium (K)									
0	107	73.8	153.1	9.6	51.6	3.67	4.5	1.82	62
1%	110	76.0	151.7	10	53.2	3.78	4.72	1.94	62.9
Control vs rest									
Control	112	80.2	160.3	10.7	53.9	3.94	4.85	2.13	72.1
Rest	108	74.9	152.4	9.8	52.4	3.78	4.72	1.88	62.4
Interactions									
ST x STR	ns	ns	ns	ns	Ns	ns	ns	ns	ns
ST x K	ns	ns	ns	ns	Ns	** (Fig. 6)	ns	ns	** (Fig. 12)
STR x K	ns	ns	ns	ns	Ns	ns	ns	ns	ns
V x ST	ns	ns	ns	ns	** (Fig. 5)	** (Fig. 7)	** (Fig. 11)	** (Fig. 8)	** (Fig. 13)
V x STR	ns	** (Fig. 3)	ns	ns	Ns	ns	ns	ns	ns
V x K	ns	** (Fig. 2)	ns	ns	** (Fig. 4)	ns	** (Fig. 10)	**(Fig. 9)	ns
ST x STR x K	ns	ns	ns	ns	Ns	ns	ns	ns	ns

Mean followed by different letters within a column and category are significantly different from each other ($p<0.05$) using Least Significant Difference (LSD) test
Where ** = Significant and ns = non-significant

Growth of the tillers that is mainly during vegetative stage, whereas the elongation at slow rate was observed and at the time of floral initiation maximum plant height is attained, reduction in plant height with stress imposition at garin filling stage more than other stages. It was described by Zhao et al., (2006) that water stress influenced height of the plant because of imbalancement in hormones that ultimately influenced growth due to variations in the extension of cell wall. The deleterious influence of water deficit may also be reduced by increasing water to the plant due to decrease in transpiration rate by closing of stomata partially (Hoad et al., 2001). It has been recommended that plants mineral nutrient status plays a crucial part in enhancing the tolerance of plant to water stress imposition (Yadov 2006). Among the mineral nutrients, potassium vital role is to improve the plant resistance to water stress imposition. For varying physiological methods, such as enzymes activation, photosynthesis, maintenance of turgescence, photosynthates translocation, K is important element (Mengel and Kirkby, 2001). The exogenous application of K enhanced the plant height as stated by Aown et al., (2012).

Days to physiological maturity were significantly ($p\leq 0.05$) influenced by water stress, stress application stages and varieties as compared to potassium spray which was non-significant (Table 1). The planned mean comparison of control vs rest was also significant with maximum for control treatment and interactions were non-significant. Maximum days to physiological maturity were recorded for Pakhtunkhwa-2015 as compared to Lalma. Among the different stress application stages of the crop, maximum days to physiological maturity were noticed when stress was applied at tillering stage followed by stress application at grain filling while minimum days to physiological maturity were recorded for tress application at grain filling stage. While averaged across the stress levels, maximum days to physiological maturity were counted for mild stress as compared to severe stress. This may be due to the water stress occurred at three critical growth stages of the crop, hence the plant tends to complete its life cycle or bypass some stages for stress escape. In varieties, the reason for maximum and minimum days to anthesis could be genetic make-up of the varieties. Similar results have also been described by Hafid et al., (1996). These results agree with those reported by Saleem (2007) and Mohamed (2013) who reported that increasing drought stress decreased days to maturity. Potassium foliar application delayed days to maturity, reason might be the role of potassium as stress tolerant and maintenance of plant physiological and biochemical processes under stress conditions.

Yield traits

Water stress, stress application stages, Potassium foliar spray and varieties significantly ($p \leq 0.05$) affected spike length of wheat (Table 1). Maximum spike length was measured for Lalma as compared to Pakhtunkhwa-2015 of wheat crop. Among the different stress application stages, maximum spike length was measured when stress was applied at grain filling stage as compared to stress application at flowering stage which was statistically similar with stress application at tillering stage of wheat. The maximum and minimum spike length was recorded for mild and severe stress respectively. Likewise, maximum plant height was measured for Potassium foliar spray (1 %) as compared to no spray. Length of the spike was severely affected by water deficit at any growing phase like tillering, flowering and grain filling. Minimum spike length was measured when water stress was withheld at flowering and maturity phase rather than the vegetative stages. All possible interactions were non-significant. Giunta et al., (1993) also stated that water deficit severely reduced spike length between stem elongation and ear formation stage. The minimum length of spike at anthesis is due to fewer number of nodes and a reduced amount of node to node distance on the rachis of the spike. Furthermore, it was also detected by Yadav et al. (2004) that under environmental stress conditions the spike length remains unchanged. The results are in line with Mollah and Paul (2011) who found that spike length increased with the increase of irrigation. Similarly, Alderfasi and Refay (2010) reported that low water supplies treatments reduced spike length of wheat. Application of foliar potassium significantly increased the spike length (Shekhawat et al., 2013). Mesbah (2009) and Aown et al., (2012) recommended that plant resistance to water stress imposition is increased with the application of potassium which plays a vital role.

Stress application at different stages, Potassium foliar spray and varieties significantly ($p \leq 0.05$) affected grains number spike^{-1} of wheat while non-significantly affected by stress levels i.e. mild and severe stress. The planned mean comparison of control versus rest was also significant. Data showed that maximum numbers of grains spike^{-1} were noticed for variety Lalma. Similarly, maximum grains spike^{-1} were recorded when stress was applied at grain filling stage as compared to stress application at flowering stage which was statistically similar with stress application at tillering stage of wheat. Likewise, maximum number of grains spike^{-1} were observed for Potassium foliar spray (1 %) as compared to no spray. Mean values for control vs. rest indicated statistical differences for grains spike^{-1}. The interaction of V x K (Fig. 4) and V x ST (Fig. 5) had significant effect on grains per spike of wheat.

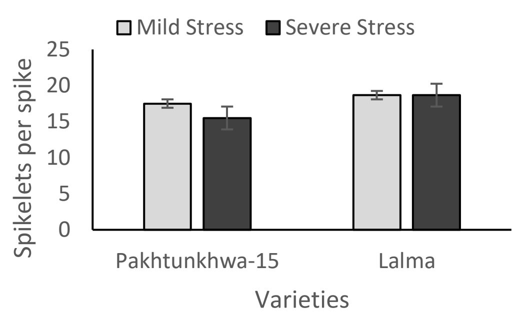

Figure 4; Interaction of V x K for grains per spike of wheat crop.

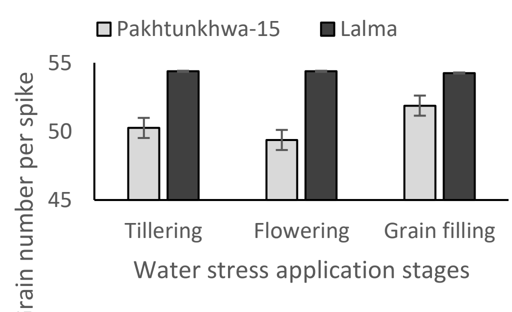

Figure 5; Interaction of V x ST for grains per spike of wheat crop.

Variety Lalma showed uniform behavior to foliar spray and also showed uniform behavior at all the water stressed imposed stage. It is the genetic potential of a variety or due to the environmental stresses that varieties differ in producing grains numbers. The response of varieties to withholding water stress shows that stress resistance ability of wheat varieties. These outcomes are in line with Svihra and Mudecova (1986) who stated that grain weight and grains number per spike decreased under water stress. Number of grains per spike were severely affected by water stress at any growth stages with less number when stress was imposed at flowering stage. At flowering or grain filling stage water stress severely influenced plant performance by causing drastic reduction in number of grains per spike (Rad et al., 2005 and Nasri, 2005). Richards et al. (2001) also stated that the grains per spike were reduced drastically under water deficit condition. The flowering stage seemed to be the most vulnerable stage to water stress withholding and resulted in less grains per spike and less number of flowers to form seed (Dejan et al., 2002). The minimum number of grains may be due to less number of spikelet per spike and spike length as reported by Plaut et al. (2004) under drought. Water stress reduced photosynthesis and ultimately resulted in reduced grains per spike and other yield contributing traits (Foulkes et al., 2001; O'Connell et al., 2004; Brisson and Casals, 2005).

Maximum seed weight was measured for variety Lalma as compared to Pakhtunkhwa-2015 variety of wheat crop shown in Table 1. Among the different stress application stages, maximum seed weight was measured when water stress was imposed at grain filling stage followed by stress application at flowering stage while lower seed weight was noticed with stress imposition at tillering stage. Differences were also found in seed weight for stress levels, high seed weight was noticed for mild stress as compared to severe stress. Likewise, high seed weight was observed for Potassium foliar spray (1 %) as compared to no spray. Control vs. rest indicated statistical differences for seed weight of wheat. The interaction of ST x K (Fig. 6) and V x ST (Fig. 7) had significant effect on hundred grain weight

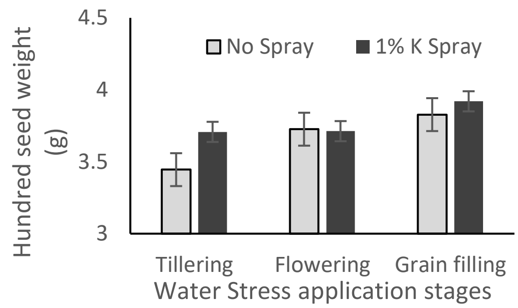

Figure 6; Interaction of ST x K for grains weight (g) of wheat crop.

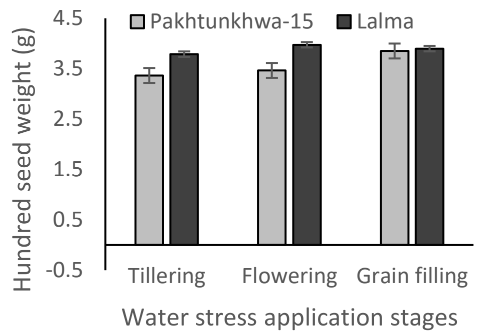

Figure 7; Interaction of V x ST for grains weight (g) of wheat crop

. Both the varieties of wheat showed better performance to foliar spray at grain filling stage. Variety Lalma showed uniform behavior to water stress application at all the three growth stages. Water stress during spike emergence and anthesis has declared to decrease grain yield up to 20% mainly through decrease in individual grain weight as reported by Hagyo et al. (2007). Water deficit may cause decrease in flow of the nutrients thus influencing the uptake and movement of mineral element in plant which finally decreased the plant growth and development (Pettigrew, 2004). These results are similar the results of Sharif (1999), Mosaad et al., (1995), Jaleel et al., (2008) and Yang et al., (2001) that imposing water decreased seed weight in different wheat genotypes. This effect of water stress during grain filling on grain yield may be due to the reduction in rate and duration of filling processes and causing small grain size consequently reducing yield components as reported by Zareian et al., (2014). Drought stress withholding during later stages may cause decrease in number of kernels/ear and kernel weight (Gupta et al., 2001; Dencic et al., 2000). The results are also in accordance to Anjum et al. (2011) who declared that water stress decreased grain weight. Aown et al., (2012) found that the water deficit caused significant influence on thousand grain weight of wheat. Potassium application as foliar significantly enhanced the 1000-grain weight. The crop resulted heaviest grains weight in control where no stress was imposed at any stage.

Biomass and yield

Stress application stages, water stress, Potassium foliar spray and varieties significantly ($p \leq 0.05$) affected biological yield (g $plant^{-1}$) of wheat as given in Table 1.. Maximum biological yield was observed for variety Lalma as compared to Pakhtunkhwa-2015. Among the different stress application stages, maximum biological yield was recorded when stress was applied at grain filling stage as compared to stress application at flowering stage which was statistically similar to where stress was applied at tillering stage. Stress levels also differs significantly for biological yield, with maximum and minimum biological yield was observed for mild and severe stress respectively. Likewise, maximum biological yield was observed for Potassium foliar spray as compared to no spray. Mean values for control vs. rest indicated statistical differences for biological yield (4.58 vs 4.61 g $plant^{-1}$). The interaction of V x ST (Fig. 8) and V x K (Fig. 9) had significant effect on biological yield of wheat.

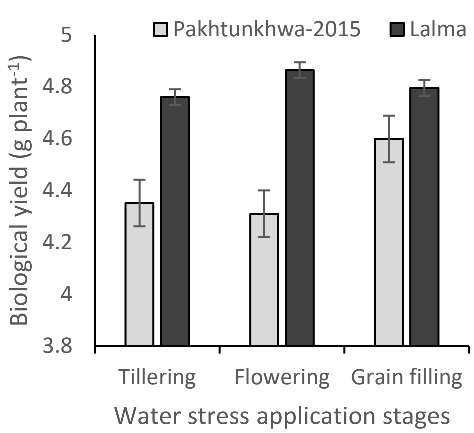

Figure 8; Interaction of V x ST for biological yield (g plant $^{-1}$) of wheat crop.

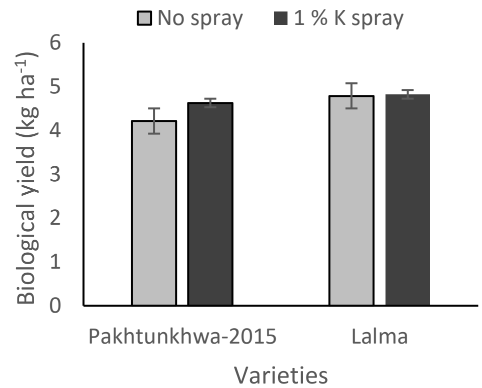

Figure 9; Interaction of V x K for biological yield (g plant $^{-1}$) of wheat crop.

Maximum biological yield was noticed for Variety Lalma by stress application at different stages and potassium foliar spray. In varieties, the reason for varying biological yield could be genetic makeup of the varieties. Similar results have also been reported by Hafid et al., (1996). Water stress at various growth stages had significant reduction in biological yield as compared with full irrigation. Imposing water stress at flowering causes greatest reduction in biological yield. The reduction in biological yield was related by reduction in grain yield and straw yield. Similar findings were reported by Kandil (2001), El-Sayed (2003), Kassab (2004), Saleem (2007), Bayoumi (2008), Sarwar (2010), Seleiman (2011), Abro (2012), Mohamed (2013), Zarein (2014) and Aslam (2014). Results are also similar with the outcomes of Wang et al. (2004) that irrigation regimes at different crop growth phases influenced different wheat varieties for biological yield. Drought stress attained by a wheat crop during growth stages is known to have combined influence expressed as a reduction in total biomass as compared to no water deficit conditions (Mirbahar et al. 2009). The foliar application of nutrients especially K provided linear increments in mass of yield of wheat (Zhao et al., 2006). The highest biological yield recorded by foliar application of KCl along with nitrogen is also reported. Foliar application of K increased the biomass yield which supports the research findings of Defan et al., (1986).

Grain yield (g $plant^{-1}$) of wheat as influenced by potassium spray under water stress is given in Table 1. Stress application stages, water stress, Potassium foliar spray and varieties significantly ($p \leq 0.05$) affected grain yield of wheat. Maximum grain yield was observed for variety Lalma as compared to Pakhtunkhwa-2015. Among the different stress application stages, maximum grain yield was recorded when stress was imposed at grain filling stage followed by stress application at tillering stage while minimum grain yield was recorded when water stress was imposed at flowering stage. Differences were noticed for stress application levels with maximum and minimum grain yield was observed for mild and severe stress respectively. Likewise, maximum grain yield was observed for Potassium foliar spray (1 %) as compared to no spray. Mean values for control vs. rest indicated statistical differences for grain yield (2.13 vs 1.88 g plant^{-1}).

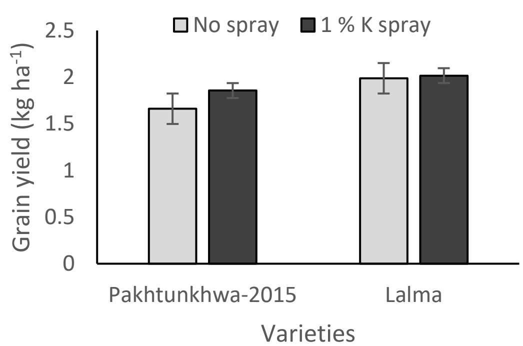

Figure 10; Interaction of V x K for grain yield (g plant $^{-1}$) of wheat crop.

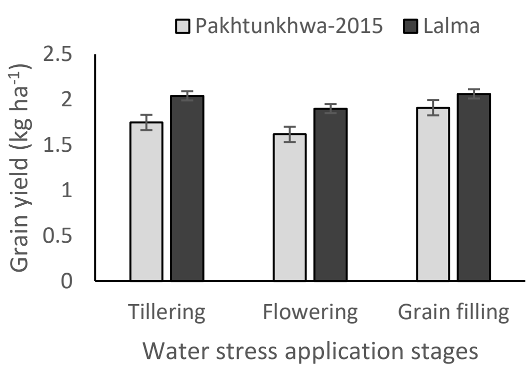

Figure 11; Interaction of V x ST for grain yield (g plant $^{-1}$) of wheat crop.

The interaction of V x K (Fig. 10) and V x ST (Fig. 11) had significant effect on grain yield of wheat. Maximum grain yield was recorded for Variety Lalma by stress application at different stages and potassium foliar spray. Variety lalma shows uniform behavior to water stress levels at all stages, although grain filling stage more responsive. In varieties, the reason for varying grain yield could be genetic make-up of the varieties. Similar results have also been reported by Hafid et al., (1996). For ideal crop growth and development normal number of irrigations are required nonetheless when there is limited supply of water, that irrigation should be skipped which cause minimum loss in yield of wheat. Efficient water use is necessary for final grain yield of wheat (Sun et al., 2006). Photosynthetic rate could be increased by normal water application at flowering stage and grain filling duration is increased (Zhang et al., 1998). Application of water stress at flowering decreased yield components as stated by Saleem (2003). Gupta et al., (2001) also concluded that water deficit at flowering reduced grain yield per plant. Drought stress resulted in minimum 1000 grain weight, grain yield, number of grains per spike and other yield contributing attributes by decreasing photosynthetic efficiency (Foulkes et al., 2001; O'Connell et al., 2004; Brisson and Casals, 2005). Pollination is reduced by stress imposition at anthesis and thus number of grains formed are less per spike which showed in the decrease of grain yield (Ashraf, 1998). Optimum water at or after anthesis period not only allows the plant to enhance photosynthesis process but also gives extra time to translocate the assimilates to the grains (Zhang and Oweis, 1998) which enhances grain size and thus lead to increase grain yield. Similar results were also revealed by Mollah and Paul (2011) who stated that grain yield improved with increasing the irrigation. Alderfasi and Refay (2010) concluded that low water supplies treatments decreased grain yield of wheat. Anjum et al. (2011) and Brisson and Casals (2005) suggested that yield components and yield experiencing water stress can be enhanced by increasing plants stress resistance. Potassium plays key role improving the plant tolerance to water stress conditions (Mesbah, 2009; and Aown et al., 2012). Similarly, Shekhawat et al., (2013) revealed that application of K2O markedly enhanced the grain yield.

Relative water content (%)

Stress application stages, water stress, Potassium foliar spray and varieties significantly ($p \leq 0.05$) affected relative water contents of wheat as presented in Table 1.. High relative water contents was observed for variety Pakhtunkhwa-2015 as compared to Lalma. Among the different stress application stages, highest relative water contents were measured when stress was applied at tillering stage followed by stress application at flowering stage while lowest water contents was observed when stress was applied at grain filling stage of the crop. Differences were noticed by stress application with higher and lower values for relative water contents were observed for mild and severe stress respectively. Likewise, maximum relative water contents were observed for Potassium foliar spray (1 %) as compared to no spray. Mean values for control vs. rest indicated statistical differences for relative water contents of the crop (72.9 vs 62.4). The interaction of ST x K (Fig. 12) and V x ST (Fig. 13) had significant effect on grain yield of wheat.

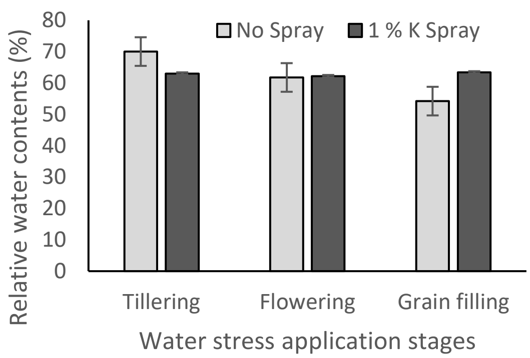

Figure 12; Interaction of ST x K for relative water content (%) of wheat crop

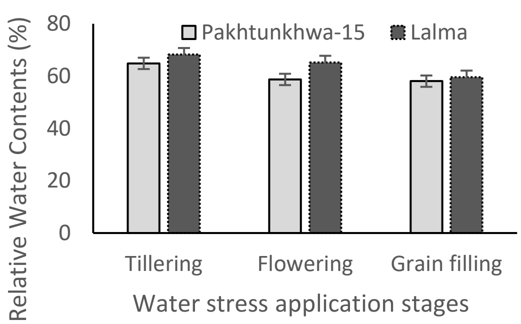

Figure 13; Interaction of V x ST for relative water content (%) of wheat crop.

Relative water contents were observed maximum for variety Lalma by stress application at grain filling stage as compared to Pakhtunkhwa-2015. Potassium foliar application enhanced relative water contents of the variety Lalma. Relative water content is considered as one of the easiest agricultural parameters that can be used to screen for plants drought tolerance. Drought tolerant plant species keep high RWC compared with drought-sensitive species in cultivars Stoyanov et al., (2005) reported that water stress causes a decrease in RWC in beans species. Recently, Balouchi et al. (2010) found that water stress could reduce the RWC in seven out of eight of the Australian wheat cultivars with clear differences between cultivars. Similarly, Tambussi et al., (2000) reported that cultivars of wheat under water stress showed a decrease in the RWC. However, Kraus et al., (1995) noted that there is a difference in RWC between drought-resistant and drought-susceptible wheat cultivars. Same variety behaves differently in terms of relative water contents for control, mild and severe stress applied at various stages of the crop growth. Results are similar with the outcomes of Husman et al., (2000), Farooq et al., (2008), and Jaleel et al., (2008) that imposing stress in crop growth phases in wheat cultivars severely decreased water status of the plant. Optimum potassium status may enable osmotic adjustment, which sustains higher turgor pressure, relative water contents (RWC) and lower Ψs, thus enhancing the performance of plants to withstand under water deficit (Egilla et al., 2005). Firstly, the alterations in water relation features reproduce the changes between species and cultivars and are considered as an indicator of drought tolerance or adaptation to drought (Ashraf et al., 1994). It is known that decrease in RWC has influenced the growth and yield of the plants as stated by Hafid et al., (1998).

CONCLUSION

It is concluded that water stress decreased grain yield about 11.07 %, 12.74 % and 6.74 % for tillering, flowering and grain filling stages respectively. Among the stress levels severe stress decreased yield by 12 % and its attributes, although Variety Lalma performs better to both stress levels at any stage of the crop compared with Pakhtunkhwa-2015. Potassium foliar application at all the three critical growth stages improved yield and all the yield components; grain filling stage was more responsive.

Based on the results it is recommended that Water should be applied to the wheat crop at critical growth stages like flowering and grain filling. In case of water shortage at any stage of the crop growth either by unavailability of irrigation or rainfall, potassium foliar application (1 %) is recommended for higher wheat yield and its components by mitigating the adverse effects of water stress. Wheat variety Lalma should be sown in areas where there is non-or less availability of irrigation due to its withstanding potential against water stress at any stage of growth.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

Nawab Ali, Amir Zaman Khan and Guldaraz Khan designed the experiment. N. Ali, M.M. Anjum and G.R. Khan collected data. H. Nawaz, S. Ali, M. Ali, S. Iqbal and Ibadullah helped in collection of experimental materials and helped in data collection and compilation. N. Ali wrote the Manuscript. A. Z. Khan and G. D. Khan reviewed the manuscript.

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