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Effects of Fertilizer Potassium on Growth, Yield and Nutrient Uptake of Wheat (*Triticum aestivum*) under Water Stress Conditions

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Abstract

Water stress causes serious yield loss of wheat (*Triticum aestivum*) under non-irrigated conditions. This study was initiated to analyze whether potassium fertilizer improves the water stress tolerance, in terms of growth, yield and nutrient uptake of this crop. Satabdi, a popular wheat variety in Bangladesh, was grown in pots with nutrient poor soils inside a plastic greenhouse under natural light. Three levels of potassium (low: 39.0, medium: 156 and high: 312 kg ha^{-1}) and three levels of soil moisture, namely control (less than 25% depletion from field capacity, FC), mild stress (more than 37.5% depletion from FC) and severe stress (more than 50% depletion from FC) were the treatment variables. Water stress affected significantly dry matter accumulation in leaf, stem, spikes and roots. The uptake of N, P and K was lowered by the water stress. Consequently, most of the yield contributing characters as well as grain yield was reduced substantially. Higher levels of K improved the dry matter production in different plant parts. Yield and yield contributing characters of wheat were also improved due to high level of K application irrespective of the levels of soil moisture. Uptake of N, P and K was also enhanced with the increasing levels of K especially under water stress conditions. It was concluded that application of high level (greater than recommended dose) of potassium might mitigate the deleterious effects of water stress on wheat productivity.
Key words: drought tolerance, dry matter distribution, potassium, wheat productivity

Introduction

Wheat (*Triticum aestivum* L.) is the second important cereal next to rice in Bangladesh. The consumption of wheat is increasing with the increasing of food diversity in the country. Presently, the crop covers an area of about one million hectares and produces about 2 million tons of grain (ANON 2003). Average production of this crop in Bangladesh is, however, low (2 t ha^{-1}), compared to other wheat growing countries. One of the major causes for low yield is the shortage of water during growing season. The crop is

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mainly grown under non-irrigated conditions during dry winter (November to March). Although the vast storage of soil moistures, resulted from monsoon rains, supports the plant growth favorably at the early stages of growth, the plant suffers from water stress at the reproductive stage when the residual soil moisture depletes (KARIM *et al*. 2000). BOYER (1982) claimed that water stress limited global crop productivity more severely than that caused by any other environmental stresses.

Water stress adversely affects plant establishment, and thereafter growth and development. Cell enlargement, gas exchange and assimilates partitioning are hindered by the stress. Under extreme conditions, it may severely disturb several metabolic processes, which may result in diminished photosynthesis, checked cell enlargement and division, and finally cell death (KRAMER 1983). Water stress at the reproductive stage is more harmful to plant processes than that at any other growth stages. This is because water stress at anthesis markedly reduces photosynthesis, reproductive development and finally grain yield (KARIM *et al*. 2000, ARAUS *et al*. 2002).

Potassium is reported to improve water relations as well as productivity of different crops under water stress conditions (JOHNSON 1983, ISLAM *et al*. 2004). MENGEL and KIRKBY (1987) reported that several biochemical pathways, osmotic potential, translocation process, and growth and maintenance of a cell are dependent on potassium ion in the cell sap. However, non-judicious application of potassium fertilizers in the field may create harmful effects on crop productivity as well as environmental problems. In this study, an attempt was undertaken to elucidate the effects of potassium on the pattern of dry matter accumulation, nutrient uptake and productivity of wheat under water stress conditions.

Materials and Methods

A pot experiment was carried out inside a plastic greenhouse under natural light at the Bangabandhu Agricultural University during winter (November 2002 to April 2003). Satabdi, a popular wheat variety, was used in this study. The treatments consisted of three levels of fertilizer potassium K, namely 39 (low), 156 (medium; recommended dose in Bangladesh) and 312 (high) kg ha^{-1} (0.27, 1.08 and 2.16 g pot^{-1}) and three levels of soil moisture, namely control (less than 25% depletion from field capacity, FC), mild stress (more than 37.5 % depletion from the FC) and severe stress (more than 50% depletion from FC). The soil could hold about 30% moisture at field capacity.

Wheat seeds were sown on 10 November 2002 in each earthen pot (30cm × 24cm) containing 14.5 kg air-dried nutrient poor sandy loam soil. When needed, the soil contained 0.064% of total nitrogen, 27 ppm of available P and 0.05 meq $100g^{-1}$ dry soil of exchangeable K and had a pH of 5.6. The doses of N, P, S and B were 215, 100, 139 and 6 kg h^{-1}, respectively (recommended doses). Fifty percent of N and K, and whole amount of P, S and B were applied at the time of sowing. The rest 50% of

N and K were applied at 35 days after sowing. All the nutrient elements were used in the form of their respective available commercial fertilizers.

Soil moisture levels were monitored throughout the growing period by weighing three randomly selected pots for each treatment everyday. When needed, the required amount of water was added to each pot to maintain the respective moisture level. One plant was grown in each pot. Plant protection measures were taken to keep the plants free from pests and diseases.

At anthesis four plants from each treatment were harvested. The plant was separated into leaf blade, leaf sheath, stem, spike and roots. The samples were oven-dried to a constant weight at 70℃ for 72 hours and the dry weights of the different parts were recorded separately.

Number of effective tillers plant^{-1}, number of spikelets spike^{-1}, number of grain spike^{-1}, number of grain plant^{-1}, 100-grain weight and grain yield plant^{-1} were recorded from eight replicated plants at maturity.

Oven dried whole plant materials at final harvest were ground with a Willey grinding machine for the estimation of different mineral ions. Estimation of total nitrogen was done by colorimetric method following LINDER (1944). Total P was determined after digestion of the samples with nitric-perchloric acid according to the method of YAMAKAWA (1992). K was determined by atomic absorption spectrophotometry (170-30 Hitachi; Hitachi Corp., Tokyo, Japan) according to the method of UMEZAWA *et al*. (2001). Each element was measured using 4 plants.

The experiment was consisted of three levels of both moisture and potassium. The data recorded for different parameters were statistically analyzed using the "MSTAT" program. The differences between the treatment means were compared by the Least Significant Difference (LSD) test at 5% level of significance after performing ANOVA (GOMEZ and GOMEZ 1983). Data on each experimental plot were shown, because the interaction between water stress and K was found to be statistically significant in most of the measured parameters.

Results and Discussion

Dry matter accumulation in different plant parts

Dry matter accumulation in different plant parts is shown in Fig 1. Both leaf blade and sheath dry weight decreased significantly, in a similar pattern, with the increasing levels of water stress (Fig. 1a,b). Severe and mild levels of water stress reduced 84% and 58% leaf dry weight respectively (compared to the control) at the highest level of K. Leaf dry weight increased with the increase in levels of potassium. Under severe water stress conditions, both leaf blade and sheath dry weight increased almost double due to application of the highest level of K.

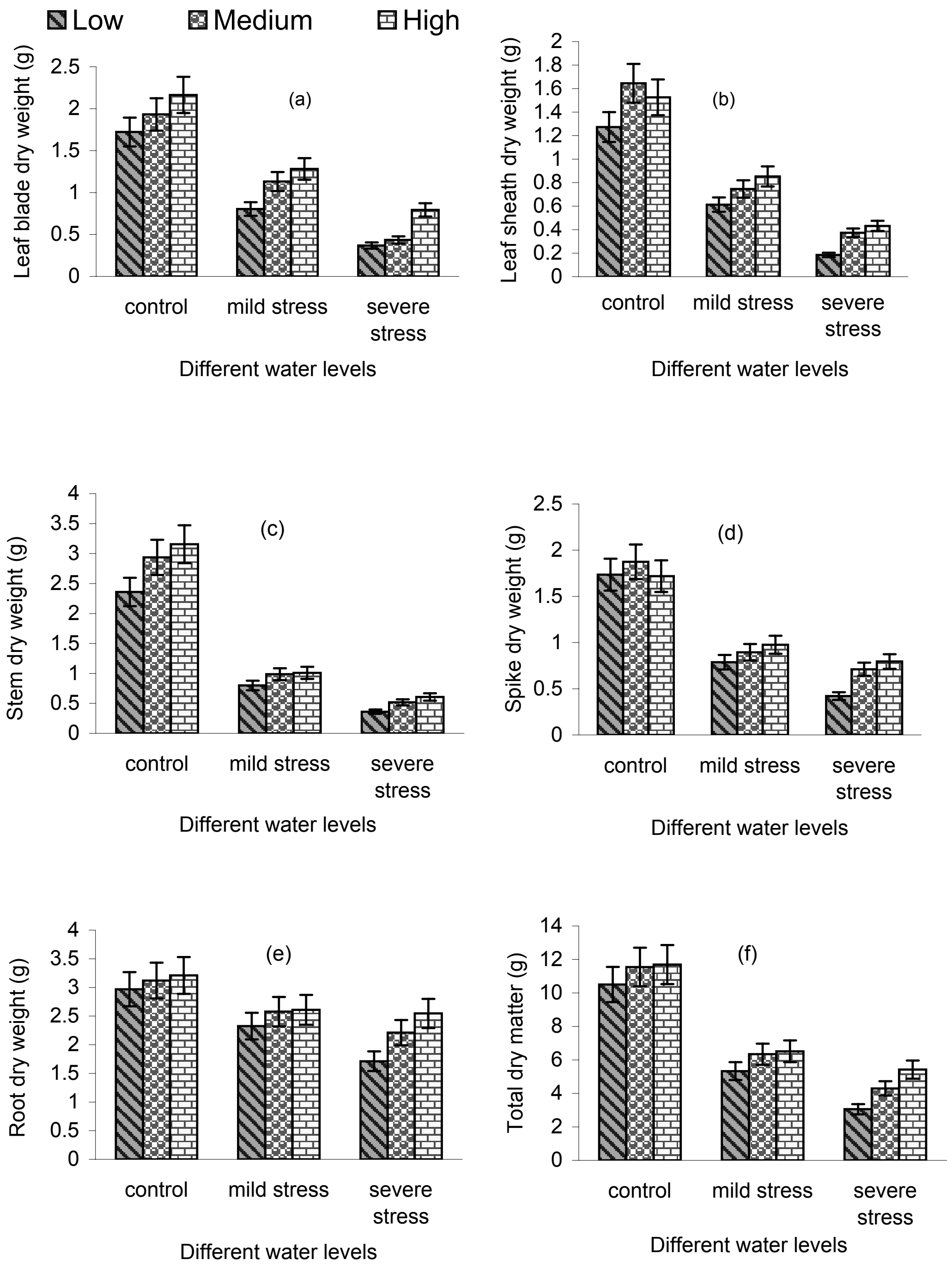

Fig. 1. Effect of fertilizer potassium on leaf blade dry weight (a), leaf sheath dry weight (b), stem dry weight (c), spike dry weight (d), root dry weight (e) and total dry weight (f) at anthesis in wheat grown at different soil moisture levels. Bars represent SE (n= 4). Low: 39 kg K/ha, Medium: 156 kg K/ha, and High: 312 kg K/ha.

Stem dry weight measured at anthesis markedly decreased with the increase in the levels of water stress (Fig.1c). Severe and mild levels of water stress reduced 85% and 52% stem dry weight, respectively at the highest level of K. The maximum stem dry weight was obtained from the plants at the control with 312kg K ha^{-1}, while the least one from severe stressed plants received 39 kg K ha^{-1}. Irrespective of soil moisture levels, external application of potassium increased stem dry weight.

Severe and mild levels of water stress reduced 75% and 55% spike dry weights, respectively at the highest level of K (Fig. 1d). Higher doses of potassium increased 86% and 24% of the weight under severe stress and mild levels of water stress, respectively. Under control condition the effect of K on spike dry weight was not clear. These results clearly indicated that the effect of potassium was more pronounced under stressful conditions than that under control conditions.

Root dry weight was also decreased due to water stress (Fig.1e). However, the reduction of root dry weight was comparatively less than that of above ground plant parts. Application of higher levels of potassium increased root dry weight. The highest amount of root dry weight was obtained with higher levels of potassium under control conditions, while the lowest one from the plant received 39.0 kg K ha^{-1} under severe stress conditions. The highest level of potassium enhanced root dry weight by 49% and 12% under severe and mild water stress conditions, respectively. However, K induced increase in root growth was small under control condition compared to that under stressed conditions.

Total dry matter (TDM) decreased severely with the decrease of soil moistures (Fig 1f). Severe and mild levels of water stress reduced 70% and 49% of TDM, respectively at the highest level of K compared to the control. With the increasing external application of potassium, total dry matter production increased significantly, especially under severe stress conditions. The highest level of K increased 78% and 22% of TDM under severe and mild stress conditions, respectively

Cell elongation is a turgor dependent process. Water stress lowers the cell turgor and causes slower cell expansion. Consequently, growth and development of a plant are decreased and that leads to a lower plant dry weight (PLAUT *et al.* 2000). KHAN *et al.* (1999) observed in wheat that drought tolerant genotypes maintained turgor by decreasing osmotic potential in a condition of lower leaf water potential due to stress. They also concluded that sugar and K^+ were the major factors affecting osmotic potential. Perhaps the high level of K contributed for the maintenance of turgor and thus improved the growth processes of the plant, which was affected due to water stress.

Uptake of mineral ions

Nitrogen uptake by the water stressed plants decreased severely. Severe and mild levels of water stress reduced 72% and 60% N uptake, respectively at the highest level of K. Application of potassium enhanced the uptake irrespective of levels of soil moisture (Fig. 2a). Earlier reports also indicated that water stress decreased nitrogen uptake in wheat (PATEL and SINGH 1998) and in rice (BARUAH *et al.* 1998). MURPHY (1980) gives an extensive review of N-K interactions on N metabolism. Plants can absorb nitrogen either as a cation or an anion form. This presents the unique possibility of both an anion-cation and a cation-cation interaction with K^+. AJAY *et al*. (1970) noticed that K^+ enhanced NH_4^+ assimilation in tomato without NH_3 toxicity and uptake of K^+ was not competitive with NH_4^+. MENGEL *et al*. (1976), working with rice (*Oryza sativa* L.), also concluded that K^+ would not compete with NH_4^+ for the same binding sites in the absorption process. In an early study, MACLEOD (1969) noticed that responses of barley to increasing nitrogen concentrations were dependent mainly on the levels of K in the whole plant sample. Response to added N was restricted unless added K^+ was sufficient.

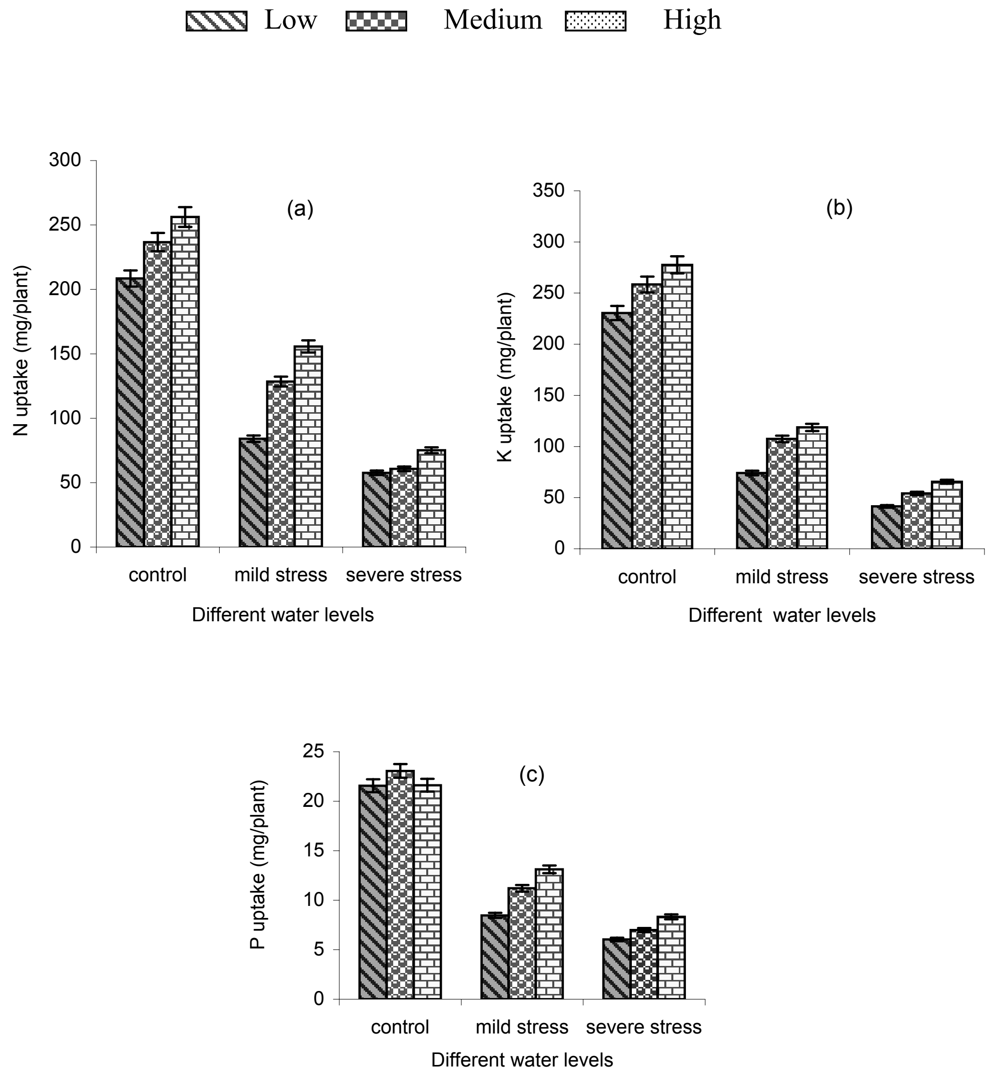

Fig. 2. Effect of potassium on nitrogen (a), potassium (b) and phosphorous (c) uptake of wheat under different soil moisture levels. Bars represent SE (n=4). Low: 39 kg K/ha, Medium: 156 kg K/ha and High: 312 kg K/ha.

Severe and mild levels of water stress reduced 82% and 67% of K uptake, respectively at the highest level of K (Fig. 2b). The least amount of potassium was measured under severe stress conditions, when the plants were received 39.0 kg K ha^{-1}. Application of potassium enhanced K uptake, irrespective of soil moisture regimes. However, K uptake was more pronounced under mild stress and severe stress conditions (60% and 58%, respectively) compared to that of control condition (20%). The reduction in potassium uptake by water stress was mainly due to reduced plant dry weight. PATEL and SINGH (1998) observed that water stress reduced the uptake of nutrients in plants, and most of N and P were accumulated in grains, while most of K in stem and leaves. HANWAY *et al.* (1985) reported that application of high level of potassium increased leaf K content of soybean under drought stress.

Water stress significantly reduced P uptake, too (Fig. 1c). Severe and mild levels of water stress reduced 72% and 61% of the uptake, respectively at the highest level of K. Application of potassium enhanced the uptake of phosphorus. The increasing trend for P uptake was observed especially in mild stressed and severe stressed plants. ASHRAF *et al.* (1998) noticed that water stress decreased Ca, Mg and P concentrations in wheat plants. BARUA *et al.* (1998) concluded that water stress significantly reduced P contents in rice genotypes and the reduction was less in tolerant genotypes than in susceptible one.

Yield and yield contributing characters

Number of effective tillers per plant was decreased with the increasing levels of water stress (Table 1). The minimum number of effective tillers per plant (1.25) was recorded under severe stress conditions with the minimum level of K. The maximum effective tillers (5.81) were recorded in plants received higher level of potassium under control conditions.

The shortest ear was recorded in the plants received minimum amount of K with severe stress. The longest one was recorded in the plants under control conditions with maximum amount of K (Table 1). Spikelet number per spike and also kernel number per spikelet were influenced by the both levels of soil moisture and potassium (Table 1).

Water stress drastically reduced number of kernels per plant. (Table 1). The reduction of kernels per plant under stress conditions was attributed to the reduction of number of effective tillers per plant. Irrespective of water stress, the increasing levels of fertilizer potassium increased the number of kernels per plant. The increasing tendency was more pronounced under low soil moisture regime than that under control conditions. The lowest number of kernels per plant (37.59) was observed in plants received the low level of potassium under severe stress conditions. The highest kernels per plant (207.44) were noticed under control conditions with the high level of potassium. Both water stress and potassium levels influenced 100-grain weight, though their interaction effect was not significant. High level of potassium increased the 100-grain weight at all levels of water stress. Grain yield (kernel weight per plant) was re-

Table 1. Effects of potassium on yield and yield contributing characters of wheat at different soil moisture levels.

Water levels	Levels of potassium (kg ha^{-1})	Effective tillers plant^{-1}	Ear length (mm)	Spikelet spike^{-1}	Kernel spikelet^{-1}	Kernel plant^{-1}	100-grain weight (g)	Kernel weight plant^{-1} (g)
Control	Low	5.31	99.29	15.31	2.28	184.75	4.65	8.96
	Medium	5.63	99.65	14.54	2.53	203.00	4.85	9.57
	High	5.81	105.76	15.83	2.30	207.44	4.92	10.09
Mild stress	Low	2.25	95.31	15.33	2.39	91.88	4.55	4.36
	Medium	2.81	97.71	15.37	2.41	99.56	4.93	4.82
	High	2.88	100.64	15.99	2.57	105.94	5.01	5.10
Severe stress	Low	1.25	92.54	15.63	2.08	37.59	4.32	1.80
	Medium	1.56	96.69	14.04	2.35	50.06	4.50	2.68
	High	1.75	103.32	15.59	2.24	59.69	4.96	2.88
LSD (0.05)		0.441	3.21	0.752	0.249	6.98	0.347	0.709
CV (%)		9.58	2.29	3.47	7.53	4.26	5.14	8.98
Sources of variation								
Soil moisture (SM)		**	**	**	**	**	**	**
Potassium (K)		**	**	**	*	**	**	**
SM x K		NS	**	**	**	**	NS	NS

Low, medium and high indicates 39.0, 156 and 312 kg ha^{-1} K, respectively. **Indicates 1% and *indicates 5% level of significance. NS= Non-significant

duced severely due to water stress. Application of potassium improved the yield irrespective of moisture levels, although soil moisture and potassium interaction effect was not significant (Table 1). Severe and mild levels of water stress reduced 80% and 51% grain yield, respectively compared to the control at the highest level of K. Yield reduction was attributed to the reduced number of effective tillers and kernels per plant. The results of this study are in conformity with the findings of KARIM *et al* (2000) that water stress reduced grain yield by reducing productive tillers per plant, fertile spikelet per plant, number of grains per plant and individual grain weight. Results from others studies also showed that stress environment reduced grain yield of wheat to a great extent (MONAYERI *et al*. 1984, KHANNA-CHOPRA *et al*. 1994, SIDDIQUE *et al*. 1999).

Potassium is a major nutrient element that plays an important role in several metabolic processes such as protein synthesis and osmotic adjustment (MARSCHNER 1995). Maintenance of high cytoplasmic levels of K^+ is essential for survival of plants in stress environment (CHOW *et al*. 1990). HANWAY *et al*. (1985) reported that application of high level of potassium increased leaf K content and seed yield of soybean under drought stress conditions. PREMACHANDRA *et al*. (1993) noticed that external application of potassium helps in the active uptake of K^+ into guard cells under stresse conditions. K is also reported to affect photosynthetic processes in two ways. First, K^+ affects photosynthetic capacity, possibly because of the dependence of protein synthesis and developmental process on K^+. Thus, the gas exchange of an expanding leaf is restricted rapidly after the onset of K^+ deficiency. Second, K appears to affect the activity of photosynthetic system, which becomes evident when a mature leaf becomes K deficient (HUBER 1985). In this regard, PEASLEE and MOSS (1968) reported that photosynthesis in K deficient corn leaves increased when K was supplied through transpiration stream. All those reports support the findings of this study that high level of K enhances plant growth and yield of wheat under water shortage conditions.

In conclusion, we demonstrated that water stress decreased dry matter accumulation in different plant parts of wheat. As a consequence, grain yield and yield contributing characters were also decreased severely. Interestingly, the high level of potassium increased the dry matter accumulation and grain yield. The contribution of high level of potassium to grain yield production was found greater under water stress conditions than under control conditions. Water stress decreased not only dry matter in plants but also uptake of the major mineral nutrients, namely N, P and K. The uptake was increased with the application of increasing levels of potassium. The enhanced uptake of the nutrients presumably improved the grain yield of the plants under water stress conditions.

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