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Yellow Maize Crop Response to Potassium and Boron Fertilization under Upper Egypt Conditions.

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ABSTRACT

Potassium (K) and boron (B) are essential nutrients for plant growth, yield and quality, for their roles as enzymes activities and for sugars and carbohydrate transport as well as the synergetic relationship between them. In addition, plants that are large consumers of K require B levels greater than 20 ppm in the tissue to accomplish this. Also, to achieve or maintain maximal maize yields, supplemental K and B fertilization is often required, particularly on soils testing low for native available soil K and B. So, two field experiments were carried out during the two successive summer growing seasons of 2015 and 2016 at Kom Ombo Agriculture Research Station, Aswan Governorate (Latitude 24° 47' 21.40" N, Longitude 32° 92' 47.5" E), to evaluate the response of maize crop (*Zea maize L.* c.v yellow single hybrid 168) to K and B fertilization. Treatments were carried out in a split plot design with three replicates; the main plots were assigned for 6 rates of K fertilizer: K_1 (control: without K fertilization), K_2 (24 kg K_2O fed^{-1}), K_3 (36 kg K_2O fed^{-1}), K_4 (48 kg K_2O fed^{-1}), K_5 (foliar applied 2% K_2O) and K_6 (24 kg K_2O fed^{-1}+ foliar applied 2% K_2O), and the split plots were devoted to three treatments of foliar applied B (B_0: without B, B_1: 25 mg B L^{-1} and B_2: 50 mg B L^{-1}). Results demonstrated the importance of potassium and boron fertilization for maize crop yield and its quality under the present conditions. Results showed that addition of K fertilizer rates as soil and/or foliar with boron increased maize grain yield, its components and quality. N, P, K and B concentrations and uptake in both stalk and grain were also significantly increased. Yet, interactions among K fertilization rates and foliar applied B significantly increased grain and stalk yields as well as grain contents of carbohydrate and oil. The highest grain and stalk yields (3700 and 5369 kg fed^{-1}, respectively) were recorded by the interaction of $K_4 \times B_2$ without significant differences between it and the yields recorded by the interactions of $K_3 \times B_2$ or $K_6 \times B_2$. N, P, K and B concentrations or uptake in grain and stalk increased with interaction between K and B, but these increases were only significant for K and B. On the other hand, economic evaluation of the studied treatments illustrated that the treatments of K_6 (24 kg K_2O fed^{-1}+foliar applied 2% K_2O) and K_3 (36 kg K_2O fed^{-1}) with foliar applied 50 mg B L^{-1} were the most profitable since they achieved the optimum maize grain yield under this study conditions.
Keywords: potassium, boron, maize yield, quality and Aswan Governorate.

INTRODUCTION

Maize is one of the most important cereals in Egypt that ranks the third after wheat and rice. It is used as a human food and animal feed. Maize is also considered a source of carbohydrate that used as food; in livestock diet, in the textile industry and also in the pharmaceutical industry. Moreover, maize is used in the manufacture of starch, gluten, corn oil, corn syrup, sugar, corn meal and corn flour.

Potassium (K^+) is one of the major nutrients considered essential for crop growth and yield development, although it is not an integral component of any cellular organelle or structural part of the plant. It is the most abundant cation in plants and is associated or involved with many physiological processes supporting plant growth and development. Water relations, photosynthesis, assimilate transport and enzyme activation all can be impacted by potassium (Mengle and Kirkby 2001 and William 2008). Potassium is also involved directly or indirectly in plant protein metabolism (Blevins 1985). The total amount of potassium absorbed by the crop during the growing season depends upon the crop species, the amount of native soil K^+, the amount of fertilizer K applied, K availability in the soil, the environmental conditions during the growing season and the management practices employed (Mullins and Burmester 1998 and Mengle and Kirkby 2001).

Aswan Governorate is one of the governorates of Egypt that is the southernmost governorate in Upper Egypt (23.59° N 32.82° E). Aswan has a hot desert climate. Averages high temperatures are consistently above 40 °C during summer (June, July, August and also September) while averages low temperatures remain above 25 °C. The climate of Aswan is extremely dry year-round, with less than 1 mm (0 in) of average annual precipitation (internet site: Aswan-WIKIPEDIA-2016, the free encyclopedia). With continuous planting crops that consume or require large amount of K and other nutrients such as sugar cane declined soil fertility especially their contents of K, B and other micronutrients, being limiting factors for yield and its quality; as well as sustainable soil fertility and its crops production.

Numerous studies have shown that K mitigates the adverse effects of salinity and drought on plant growth. In this respect, Marschner (1995) and Sanjakkara *et al*. (2001) showed that application of K reduces the adverse effects of salinity through its role in stomata regulation, energy status, charge balance, protein synthesis and homeostasis. Also, Cox (2001) showed that potassium consumption distinguish the corn roots to develop well and have powerful enough to absorb water from the soil. Therefore, potassium increased resistance capacity against drought that increased growth of corn plant. Wiebold and Scharf (2006) showed that potassium regulates stoma closure and prevents water wasting, regulats osmosis, increases water use efficiency and improves growth condition in corn under drought. Zhang *et al*. (2014) illustrated that K mitigate the adverse effects of drought stress; through increasing dry matter across all growth stages and maize grain yield. Additionally K application increased relative water content, nitrate reductase activity, and concentrations of K ion, free proline and soluble protein in both maize cultivars.

Concerning the effect of potassium on maize growth and yield, many researchers reported that maize yield responses to K fertilization (Heckman and Kamprath 1992; Mallarino *et al*., 1999 and Ebelhar and Varsa 2000). Allan *et al*. (1998) demonstrated that maize hybrids differ in K uptake efficiencies, with the more efficient K-uptake hybrid was also being the highest yielding. Tabatabaii, *et al*., (2011) found that application of potassium sulphate fertilizer under drought stress condition increased grain yield and 1000-grain weight up to 200 kg K/ha (84 kg K fed^{-1}). Moreover, Ahmad *et al*., (2012) found that application of K levels (0, 40, 60, 80 and 100 kg K/fed) to maize hybrids (pioneer 3012, pioneer-3062, pioneer-30D55) increased potassium use efficiency (KUE) significantly at all levels over control, and the highest KUE was 2.77 kg yield/kg K at K-level 80 kg/fed. In a field study (at middle texture soil, pH 6.18 and medium available K content- 184 ppm), Radulov *et al*., (2012) showed that high doses of K and phosphorous (150 kg K_2O and 150 kg P_2O_5/ha) on plots pre-fertilized with small and fairly large amounts of nitrogen (0 and 50 kg/ha) led to increased level of starch in the grains of corn. Abd El-Rheem *et al*., (2015) found that increasing K fertilization (40-60 kg K_2O/fed) had a positive effect on increasing maize growth and yield parameters and this effect was more pronounced as the P fertilization level (40, 60 and 80 kg P_2O_5/fed) increased.

Boron is one of the 6 essential micronutrients, i.e. Fe, Mn, Zn, Cu, B and Mo. Uptake of B by plants correlates well with hot water soluble B extracts of soils. Boron deficiencies occur over a much wide range of soils and crops. These deficiencies are mostly found in light soils, low organic matter contents and high soil pH levels (Mengel and Kirkby, 2001). Boron affects at least 16 functions in plants. These functions include: cell wall structure, membrane stability, sugar transportation and phenol, carbohydrate, nucleic acid and IAA (indole acetic acid) metabolism; pollen germination, flowering and seed development (Marschner, 1995, Brown *et al*., 2002 and Wang *et al*., 2003).

Many studies also showed the importance of supplemented boron. Li and Liang (1997) reported that improved growth and high quality yields were attained when crops were supplied with B. Hamzeh and Florin (2014) showed that foliar application of B single or shared with other micronutrients at different growth stages have been shown to be effective in efficient consumption of B by wheat and thus increase grain sitting and increase grain yield, number of grains per spike and thousand grain weight. Mekki (2015) showed that foliar application of 300 and 600 ppm B as boric acid increased sunflower yield and seed quality, whereas the highest values of seed yield, head diameter, number of seeds/head, weight of 1000 seed, percentage of oil and oil yield $plant^{-1}$ were attained at 600 ppm B.

Boron and potassium have a synergetic relationship between them; it is clear from its roles at sugar and carbohydrate transport (Mengle and Kirkby 2001). Also, plants that are large consumers of potassium require levels of boron greater than 20 ppm in the tissue to accomplish this. Yet, heavy users of potassium in the bulking stage of production will require boron levels in the tissue in the range of 60 to 80 ppm in order to take up the potassium they require (Canada 2002). To achieve or maintain maximal maize yields, supplemental K and B fertilization is often required, particularly on soils testing low for native available soil K and B. Mahdi *et al*., (2013) showed that using balanced fertilization of potassium and boron increase grain yield of wheat, and 1000 grain weight.

So, this study aims to evaluate the response of maize crop grown under Aswan Governorate conditions to potassium and boron fertilization to achieve the optimum rates that recognized the maximum yield with quality.

MATERIALS AND METHODS

Two field experiments were conducted during the successive summer growing seasons of 2015 and 2016 at Kom Ombo Agriculture Research Station, Aswan Governorate (Latitude 24° 47' 21.40" N, Longitude 32° 92' 47.5" E), to evaluate the response of maize crop (*Zea maize L.*) to potassium and boron fertilization.

Treatments were carried out in a split plot design with three replicates, where the experimental plot area was $10.5m^2$ (5 lines x 0.60 m width x 3.5m length). The main plots were assigned for 6 rates of potassium fertilization; i.e. K_1 (control: without K fertilization), K_2 (24 kg K_2O fed^{-1}), K_3 (36 kg K_2O fed^{-1}), K_4 (48 kg K_2O fed^{-1}), K_5 (foliar 2% K_2O) and K_6 (24 kg K_2O fed^{-1} as soil application + foliar 2% K_2O). The split plots were devoted to three treatments of foliar applied boron; i.e. B_0, B_1 and B_2 (control: without foliar, 25 and 50 mg L^{-1}, respectively).

Soil samples collected from the experimental field were analyzed before sowing according to Hesse (1971), A.O.A.C. (1990) and the results are shown in Table 1. Available boron was extracted by hot water and determined spectrophotometrically using Azomethine-H method (Wolf, 1971). Electrical conductivity (EC) in soil paste extract and pH in soil: water suspension1:2.5 were measured. The results in Table (1) show that soil available K was in the medium range, while B content was in the low range.

Table 1. Some physical and chemical properties of the experiment soil before sowing (Average of the two seasons).

Properties	Particle size distribution				OM	$CaCO_3$	SP	pH	EC
	Sand %	Silt %	Clay %	Texture class	%	%			dSm^{-1}
Values	60.24	16.12	23.64	Sandy clay loam	0.48	2.4	60.0	8.15	1.21

Properties	Soluble Cations and anions (meq/100 g soil)								Available Nutrients (mg kg^{-1})			
	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}	N	P	K	B
Values	3.14	2.70	4.13	0.45	--	2.02	7.11	1.74	55	21	250	0.6

Maize seeds were sown in April 15th 2015 and harvested in August 10th 2015 in the 1st season and sown in April 10th 2016 and harvested in August 1th 2016 in the 2nd season. Nitrogen fertilizer was added at 120 kg N fed^{-1} as ammonium nitrate (33.5% N) at three doses (20 % before sowing and 40 % with the second and third irrigations). Phosphorous fertilizer was added as calcium super phosphate (15% P_2O_5) with soil preparation at a rate of 30 kg P_2O_5 fed^{-1}. Treatments of soil potassium application (K_2, K_3, K_4 and K_6) were done in one dose as potassium sulphate (48% K_2O) before the first irrigation. Foliar applied Potassium at the concentration of 2 % K_2O as potassium sulphate was added twice after 45 and 60 days from sowing and the spraying solution was 400 L fed^{-1}. Boron was foliar applied at the concentrations of 25 and 50 mg B L^{-1} (with spraying solution 400 L fed^{-1}) as boric acid twice after 55 and 70 days from sowing. The field experimental plots were surface irrigated in lines every 8 days.

At harvest, plants from each plot were collected and yield parameters were recorded; Plant height (cm), ear weight (g plant^{-1}), grain yield (kg fed^{-1}), 1000-grain weight (g) and dry weight of stalk yield (kg fed^{-1}). Samples of grains and stalks were taken randomly from each plot for chemical analysis to determine nitrogen, phosphorus and potassium concentrations; carbohydrate % and oil % in grains according to A.O.A.C. (1990). Protein content was calculated as follows: (Protein % = N % in grain × 5.70). Nitrogen was determined by Kjeldahl method, phosphorus was determined spectrophotometrically and potassium was determined using flame photometer. Boron concentration in both grain and stalk was determined colorimetrically using Azomethine-H method as mentioned before (Wolf, 1971).

The statistical analysis was done according to Gomez and Gomez (1984) and means of treatments were compared against least significant differences test (L.S.D.) at level 5%.

RESULTS AND DISCUSSION

Effect of K and B Fertilization and Their Interactions on:

1-Maize Yield and Its Components:

Data in Table 2 show that the addition of K-rate up to K_3 (36 kg K_2O fed^{-1}) significantly increased plant height, ear length, ear diameter and No. of rows/ear, however increasing K-rate to K_4 and K_6 treatments caused insignificant increases in plant height, ear length and ear diameter compared with K_3, but number of rows/ear was significantly increased up to K_2 without specific trend with the other K-rates. Also, data in Table 3 illustrate that 1000-grain weight, ear weight, grain and stalk yields were significantly increased with the application of K-rates. K_4 treatment (48 kg K_2O fed^{-1}) achieved the highest values of 1000-grain weight (299 g), ear weight (213 g), grain yield (3520 kg fed^{-1}) and stalk yield (5168 kg fed^{-1}). Moreover, the differences among the values attained with K_3, K_4 and K_6 treatments were insignificant for 1000-grain weight and ear weight. Yet, the difference between K_4 and K_6 was insignificant for grain and stalk yields showing that 24 kg K_2O fed^{-1} (50 kg potassium sulfate fertilizer) could be substituted by two foliar sprays of 2% K_2O solution. It is obvious from results in Tables 2 and 3 that K fertilization as foliar application only at 2% K_2O (K_5) was not sufficient to recognize the optimum values of yield and its components compared with the other K-rates i.e. K_2, K_3, K_4 and K_6.

Table 2. Impact of potassium and boron fertilization and their interactions on maize plant height and characteristics of ear at harvest (Average of the two growing seasons).

Treatments	Plant Height (cm)				Ear Length (cm)				Ear Diameter (cm)				No. of Rows Ear^{-1}			
	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean
K_1	162	172	191	175	18.4	20.6	21.7	20.2	3.96	4.03	4.04	4.01	15.2	15.5	15.5	15.4
K_2	191	190	200	193	20.3	21.5	22.7	21.5	4.01	4.19	4.12	4.11	15.5	16.8	16.8	16.4
K_3	197	203	204	201	21.7	21.5	23.1	22.1	4.00	4.18	4.24	4.14	15.0	16.3	15.7	15.7
K_4	198	199	206	201	22.1	23.0	23.4	22.8	4.09	4.13	4.27	4.16	16.7	15.5	17.0	16.4
K_5	181	187	195	188	20.2	22.1	21.8	21.3	4.04	4.08	4.13	4.09	14.8	16.8	16.8	16.2
K_6	196	200	208	201	22.2	20.9	23.3	22.1	4.10	4.12	4.18	4.14	15.0	15.7	16.2	15.6
Mean	187	192	201		20.8	21.6	22.7		4.03	4.12	4.17		15.4	16.1	16.3	
LSD at 5 % for:																
K	5.69				1.18				0.07				0.45			
B	Ns				0.64				Ns				0.67			
Interaction K*B	Ns				Ns				Ns				0.78			

Generally, results in Tables 2 and 3 illustrate the positive responses of K fertilization on maize yield and its components which may be attributed to medium level of available K in soil (Table 1) and to the importance of K for increasing maize yield components and then stalk and grain yields, or may be due to increasing the tolerance of plants to drought under the climatic conditions of Aswan Governorate (Cox, 2001 and Wiebold and Scharf 2006). Similar results were obtained by Tabatabaii, *et al*., (2011), Ahmad *et al*., (2012) El-Dissoky *et al*., (2013) and Abd El-Rheem *et al*., (2015).

Data in Tables 2 and 3 show also that foliar fertilization of B at 25 and 50 mg L^{-1} significantly increased ear length, number of rows ear^{-1}, 1000-grain weight; ear weight as well as stalk and grain yields fed^{-1} in favor of 50 mg B L^{-1}, while the increases in plant height, and ear diameter were insignificant. It is obvious from the results that 1000-grain weight increased by 5.45 % and 8.0 %; ear weight increased by 4.66 and 11.40 %; grain yield increased by 8.78 % and 17.15% and stalk yield increased by 7.62 and 13.57 % with foliar B_1 and B_2, respectively compared with control (B_0). So, it is clear from the abovementioned results that the increases of grain yield and its components were the highest with B_2 and the differences between B_2 and B_1 were significant. These obtained data demonstrate the response of maize crop to foliar B fertilization, which may be attributed to the low concentration of available B in the soil before sowing (as shown in Table 1) and to the important roles of boron in plant (Marschner, 1995, Brown *et al*., 2002 and Wang *et al*., 2003). These results are in accordance with many studies that showed the importance of boron for many crops such as Li and Liang (1997), Hamzeh and Florin (2014) and Mekki (2015).

Concerning the interaction effect, data in Tables 2 and 3 reveal that the interactions between K and B levels had also significant effects on number of rows ear^{-1}, grain and stalk yields, but the effects on plant height, ear length, ear diameter, 1000 grain weight and ear weight were insignificant. In this concern, the interaction of $K_4 \times B_2$ recorded the highest values of grain yield (3700 kg fed^{-1}) and stalk yield (5369 kg fed^{-1}) with relative increase percentage 62.42 % and 40.99 %, respectively compared with control (without K and B fertilization $K_1 \times B_0$). Moreover, the values of grain and stalk yields that recorded under interactions of $K_3 \times B_2$ and $K_6 \times B_2$ were insignificant with the highest values recorded with interaction $K_4 \times B_2$. These results show that interactions of $K_3 \times B_2$, $K_4 \times B_2$ and $K_6 \times B_2$ achieved the higher yields of grain and stalk, without significance differences among them under these conditions of study. These results show the integration and the balance of fertilization that happened between K and B rates that reflected on maize grain yield and its components. These results are in accordance with Canada (2002) and Mahdi *et al*., (2013) who showed the importance of balanced fertilization of potassium and boron for increasing yield.

Table 3. Impact of potassium and boron fertilization and their interactions on maize yield and its components (Average of the two growing seasons).

Treatments	1000-Grain Weight (g)				Ear Weight (g)				Grain Yield (Kg fed^{-1})				Stalk Yield (kg fed^{-1})			
	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean
K_1	250	273	280	268	174	187	191	184	2278	2574	2976	2609^d	3808	4180	4618	4202
K_2	274	286	294	285	190	205	211	202	2675	3113	3217	3001^c	4291	4853	5057	4734
K_3	282	294	305	294	192	208	226	208	3057	3244	3554	3285^b	4667	4990	5284	4981
K_4	286	301	309	299	204	209	227	213	3375	3485	3700	3520^a	4993	5143	5369	5168
K_5	271	282	289	281	194	200	211	202	2628	3054	3223	2968^c	4129	4635	4892	4552
K_6	285	301	307	298	204	206	225	212	3342	3409	3657	3469^a	4896	5026	5200	5041
Mean	275	290	297		193	202	215		2892^c	3146^b	3388^a		4464	4804	5070	
LSD at 5 % for:																
K	3.08				6.98				92.5				107.2			
B	1.74				5.99				45.8				92.6			
Interaction K*B	Ns				Ns				160.2				185.7			

K_1 (control), K_2 (24 kg K_2O), K_3 (36 kg K_2O), K_4 (48 kg K_2O), K_5 (foliar applied 2% K_2O) and K_6 (24 kg K_2O + foliar applied 2% K_2O), B_0: control, B_1: 25 mg B L^{-1} and B_2: 50 mg B L^{-1}.

2- Grain quality:

Data presented in Table 4 generally show that addition of K fertilizer rates as soil and/or foliar had significant effects on grain yield quality. In this respect, K_3, K_4 and K_6 recorded the highest values of grain contents of carbohydrate, oil and protein compared with the other K-treatments. These results illustrate the positive effect of potassium fertilization on maize grain quality that related with the importance of potassium. Potassium is involved directly or indirectly in plant protein metabolism, this involvement can begin with the stimulation of NO_3^- uptake and transport within the plant, as K^+ serves as the accompanying counter cation (Blevins 1985). Furthermore, Mengle (1980) also demonstrated that the transport of amino acids is enhanced by higher K levels, especially the transport of amino acids to developing seeds. These results are in agreement with Radulov *et al*., (2012) and Zhang *et al*., (2014).

Table 4. Impact of potassium and boron fertilization and their interactions on parameters of grain quality (Average of the two growing seasons).

Treatments	Carbohydrate %				Oil %				Protein %			
	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean
K_1	56.00	69.79	73.74	66.51	6.23	6.54	7.55	6.77	6.44	6.79	7.15	6.79
K_2	64.73	77.93	79.48	74.05	6.81	7.13	7.78	7.24	6.79	7.08	7.67	7.18
K_3	72.22	82.10	84.96	79.76	7.22	7.44	7.89	7.52	7.03	7.60	8.24	7.62
K_4	74.60	82.10	86.50	81.07	6.91	7.44	8.25	7.53	7.15	7.96	8.38	7.83
K_5	63.30	77.58	79.01	73.29	7.05	7.24	7.98	7.43	7.10	7.32	7.53	7.32
K_6	72.34	80.55	82.10	78.33	6.71	7.79	8.29	7.60	7.34	8.08	8.22	7.88
Mean	67.20	78.34	80.96		6.82	7.26	7.96		6.97	7.47	7.87	
LSD at 5 % for:												
K	1.82				0.07				0.25			
B	1.35				0.13				0.38			
Interaction K*B	3.15				0.22				Ns			

Concerning the effect of boron fertilization, data in Table 4 clearly show that the foliar addition of boron concentrations; B_1 and B_2 (25 and 50 mg B L^{-1}) had a significant effects on parameters of grain quality (carbohydrate, oil and protein percentages) with superiority for B_2. Grain contents of carbohydrate, oil and protein % were increased with increasing B-concentration, and this indicate the importance of boron for improving maize grains quality under these conditions of Aswan Governorate. Boron affects at least 16 functions in plants, such as sugar transportation and phenol, carbohydrate, nucleic acid and IAA (indole acetic acid) metabolism (Marschner, 1995). These results agreed with those obtained by Li and Liang (1997) and Mekki (2015).

Interactions among K and B rates had also significant effects on grain contents of carbohydrate and oil percentages, but had insignificant effects on protein %. Interactions of $K_3 \times B_2$, $K_4 \times B_2$ and $K_6 \times B_2$ recorded higher concentrations of carbohydrate % (86.50, 84.96 and 82.10%, respectively), oil % (8.25, 7.98 and 8.29 %, respectively) and protein % (7.72, 7.59 and 7.57%, respectively) with no significance differences among them. It is also obvious from the aforementioned results that addition of K-rates (36 or 48 kg K_2O and 24 kg K_2O+ 2 % K_2O foliar fed^{-1}) with foliar B at 50 mg L^{-1} were more effective on grain quality compared with the other treatments under study. This result may be return to that both potassium and boron have similar functions in plant (carbohydrate and sugar translocation and protein synthesis, and both of them do as enzyme activities (Marschner 1995 and Mengle and Kirkby, 2001). Also, these results show the importance of K and B supplies for improving grains quality, particularly on soils testing medium and low for native available K and B, respectively (Canada 2002) under the conditions of the present study.

3- Concentrations and contents of N, P, K and B in Grains:

Potassium effect: data in Tables 5 and 6 show that application of K-rates significantly increased N, P, K and B concentrations and contents in grain, and the highest concentrations and contents of N, P, K and B were recorded with K_4 (48 kg K_2O fed^{-1}) without significance differences compared with K_3 (36 kg K_2O fed^{-1}) and K_6 (24 kg K_2O fed^{-1} + foliar 2 % K_2O). These increases in N, P, K and B concentrations and contents correlated with the increases in plant growth and grain and stalk yields, which reflected a positive response of maize to the addition of K rates. Also these increases related with the soil analysis before sowing (Table 1), where soil had medium available K level. Yet, potassium plays important roles in plant; potassium involved in most steps of the protein synthesis, especially transport of amino acids to developing seeds (Mengle, 1980 and Blevins, 1985). These results are in accordance with those of Ahmad *et al*. (2012) and El-Dissoky *et al*. (2013).

Boron effect: data in Tables 5 and 6 illustrate that foliar spraying of B (B_1 and B_2) significantly increased N, P, K and B concentrations and contents in grain. The increases in N, P, K and B concentrations and contents were higher with B_2 (50 mg B L^{-1}) than B_1 (25 mg B L^{-1}). This result may be attributed to the importance of boron in plant; B affects at least 16 functions in plants. These functions include cell wall structure, membrane stability, nucleic acid and IAA metabolism, pollen germination, flowering and seed development (Marschner 1995, Brown *et al*., 2002, Wang *et al*., 2003).

Table 5. Impact of potassium and boron fertilization and their interactions on N, P, K and B concentrations in grain (Average of the two growing seasons).

Treatments	N %				P %				K %				B (mg kg^{-1})			
	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean
K_1	1.13	1.19	1.25	1.19	0.401	0.463	0.459	0.441	0.258	0.303	0.311	0.291	6.3	6.4	7.1	6.6
K_2	1.19	1.24	1.35	1.26	0.438	0.471	0.513	0.474	0.288	0.326	0.334	0.316	6.3	6.7	7.4	6.8
K_3	1.23	1.33	1.45	1.34	0.479	0.480	0.508	0.489	0.311	0.319	0.349	0.326	6.7	6.9	7.5	7.0
K_4	1.25	1.40	1.47	1.37	0.480	0.503	0.516	0.500	0.341	0.311	0.364	0.339	6.5	7.8	7.6	7.3
K_5	1.25	1.28	1.32	1.28	0.467	0.469	0.525	0.487	0.303	0.303	0.319	0.308	6.6	7.1	7.3	7.0
K_6	1.29	1.42	1.44	1.38	0.484	0.516	0.516	0.505	0.319	0.319	0.364	0.334	6.9	7.2	7.7	7.3
Mean	1.22	1.31	1.38		0.458	0.484	0.506		0.303	0.313	0.340		6.6	7.0	7.4	
LSD at 5 % for:																
K	0.05				0.018				0.014				0.18			
B	0.07				0.019				0.015				0.14			
Interaction K*B	Ns				Ns				0.025				0.32			

Table 6. Impact of potassium and boron fertilization and their interactions on N, P, K and B uptakes in grain (Average of the two growing seasons).

Treatments	N-uptake (kg fed^{-1})				P-uptake (kg fed^{-1})				K-uptake (kg fed^{-1})				B-uptake (g fed^{-1})			
	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean
K_1	25.7	30.7	37.3	31.3	9.1	11.9	13.7	11.6	5.9	7.8	9.3	7.6	14.5	16.6	21.2	17.4
K_2	31.9	38.7	43.3	38.0	11.7	14.7	16.5	14.3	7.7	10.2	10.7	9.5	17.0	20.8	23.7	20.5
K_3	37.7	43.2	51.4	44.1	14.6	15.6	18.1	16.1	9.5	10.3	12.4	10.7	20.4	22.4	26.7	23.1
K_4	42.3	48.7	54.4	48.4	16.2	17.5	19.1	17.6	11.5	10.8	13.5	11.9	22.0	27.2	28.2	25.8
K_5	32.7	39.2	42.6	38.2	12.3	14.3	16.9	14.5	8.0	9.3	10.3	9.2	17.2	21.7	23.6	20.9
K_6	43.0	48.3	52.7	48.0	16.2	17.6	18.9	17.5	10.6	10.8	13.3	11.6	23.1	24.7	28.2	25.4
Mean	35.6	41.5	47.0		13.4	15.3	17.2		8.9	9.9	11.6		19.0	22.2	25.3	
LSD at 5 % for:																
K	1.95				0.76				0.56				0.84			
B	2.04				0.86				0.41				0.69			
Interaction K*B	Ns				Ns				0.97				1.45			

K_1 (control), K_2 (24 kg K_2O), K_3 (36 kg K_2O), K_4 (48 kg K_2O), K_5 (foliar applied 2% K_2O) and K_6 (24 kg K_2O + foliar applied 2% K_2O), B_0: control, B_1: 25 mg B L^{-1} and B_2: 50 mg B L^{-1}.

Interaction effect: data shown in Tables 5 and 6 reveal that interactions among K and B levels significantly affected K and B concentrations and contents in grain, but had insignificant effects on N and P concentrations and contents. All values of N, P, K and B concentrations and contents in grain increased with K*B interactions. In this concern, the highest values of N-content (54.4 kg fed^{-1}), P-content (19.1 kg fed^{-1}), K-content (13.5 kg fed^{-1}) and B-content (28.2 g fed^{-1}) of grain were achieved under the interaction of $K_4 \times B_2$. Furthermore, interactions of $K_6 \times B_2$ and $K_3 \times B_2$ recorded high values of N, P, K and B contents in grain without significant differences between them and the values attained with the interaction of $K_4 \times B_2$. The rank of interactions effects was $K_4 \times B_2 > K_6 \times B_2 > K_3 \times B_2$. This rank is accordance with the effects of these interactions on maize grain yield and its components (ear weight, ear length, 1000-grain weight). These results agreed with Mahdi *et al*. (2013).

4- Concentrations and contents of N, P, K and B in Stalks:

Data in Tables 7 and 8 reveal that concentrations and contents of P, K and B in stalks were significantly increased with increasing K fertilizer rates as soil and/or foliar application. The increases in N % in stalk were insignificant, but were significant for N-uptake. For P % the increases were significant up to K_3, but for K and B concentrations the increases were significant up to K_2, without significance differences between K_3, K_4 and K_6. The highest uptake of N, P, K and B in stalk were achieved by K_4 (48 kg K_2O), without significant difference between K_3 and K_6 for N and K uptake. These results illustrate that K-rates; K_3, K_4 and K_6 were more effective for concentration and uptake of N, P, K and B in stalk. These results were in accordance with Allan *et al*., (1998) who found that maize hybrids differ in K uptake efficiencies, and the most efficient K-uptake hybrid was also being the highest yielding.

Table 7. Impact of potassium and boron fertilization and their interactions on N, P, K and B concentrations in stalks (Average of the two growing seasons).

Treatments	N %				P %				K %				B (mg kg^{-1})			
	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean
K_1	1.31	1.36	1.38	1.35	0.149	0.153	0.163	0.155	0.74	0.75	0.82	0.77	16	24	25	22
K_2	1.44	1.36	1.41	1.41	0.164	0.157	0.173	0.165	0.86	0.92	0.96	0.91	17	24	26	23
K_3	1.47	1.46	1.44	1.46	0.153	0.167	0.202	0.174	0.86	0.92	0.98	0.92	19	26	26	24
K_4	1.33	1.48	1.50	1.44	0.165	0.177	0.213	0.185	0.81	0.94	1.03	0.93	20	27	27	24
K_5	1.31	1.37	1.47	1.38	0.142	0.178	0.206	0.175	0.68	0.79	0.96	0.81	18	24	26	23
K_6	1.38	1.41	1.59	1.46	0.135	0.181	0.197	0.171	0.89	0.91	1.03	0.95	18	26	26	23
Mean	1.37	1.41	1.46		0.152	0.169	0.192		0.81	0.87	0.96		18	25	26	
LSD at 5 % for:																
K	Ns				0.015				0.046				0.8 9			
B	Ns				0.017				0.059				0.73			
Interaction K*B	Ns				Ns				Ns				Ns			

Table 8. Impact of potassium and boron fertilization and their interactions on N, P, K and B uptakes in stalk (Average of the two growing seasons).

Treatments	N-uptake (kg fed^{-1})				P-uptake (kg fed^{-1})				K-uptake (kg fed^{-1})				B-uptake (g fed^{-1})			
	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean	B_0	B_1	B_2	Mean
K_1	49.9	57.0	63.6	56.8	5.7	6.4	7.5	6.5	28.0	31.4	37.8	32.4	62	100	116	93
K_2	62.0	66.1	71.2	66.4	7.0	7.6	8.8	7.8	36.8	44.5	48.8	43.4	74	118	133	108
K_3	68.5	73.0	76.1	72.5	7.1	8.3	10.7	8.7	40.0	45.8	51.6	45.8	89	128	140	119
K_4	66.5	75.9	80.7	74.4	8.3	9.1	11.4	9.6	40.5	48.4	55.4	48.1	99	137	143	127
K_5	53.7	63.6	71.8	63.1	5.9	8.3	10.1	8.1	28.1	36.5	47.1	37.3	75	112	125	104
K_6	67.4	71.1	82.6	73.7	6.6	9.1	10.2	8.6	43.8	45.7	53.6	47.7	89	129	137	118
Mean	61.3	67.8	74.3		6.8	8.1	9.8		36.2	42.1	49.1		81	121	132	
LSD at 5 % for:																
K	4.19				0.79				2.64				4.1			
B	6.44				0.80				3.27				2.6			
Interaction K*B	Ns				Ns				Ns				Ns			

K_1 (control), K_2 (24 kg K_2O), K_3 (36 kg K_2O), K_4 (48 kg K_2O), K_5 (foliar applied 2% K_2O) and K_6 (24 kg K_2O + foliar applied 2% K_2O), B_0: control, B_1: 25 mg B L^{-1} and B_2: 50 mg B L^{-1}.

Also, data in Tables 7 and 8 show that foliar B levels significantly increased P, K and B concentrations and uptake in stalk, while the increases for N % were insignificant. Foliar B application at 50 mg L^{-1} was more effective for N, P, K and B uptake compared with B_1. The increases in N, P, K and B uptake related with its concentrations and the increases in stalks yield, which may be attributed to B functions in plants (Marschner 1995, Brown *et al*., 2002 and Wang *et al*., 2003) and to the low level of available B in soil (Table 1).

Concerning interaction effect, data in the same Tables (7 and 8) illustrate that the interactions among K and B rates had insignificant effects on N, P, K and B concentrations and uptake of stalks, and the interactions of $K_3 \times B_2$, $K_4 \times B_2$ and $K_6 \times B_2$ recorded the highest values of N, P, K and B uptake in stalk yield.

Data in Table 9 show a comparison study among the effect of interactions of $K \times B_2$ on grain and stalk yields as relative increase % (RI %) and economic evaluation for yield increase to achieve the optimum yield with maximum profitability. The inputs were 280 L.E for 50 kg potassium sulphate fertilizer, 200 L.E. for foliar K and 200 L.E. for foliar B. The outputs were: 2000 L.E. for ton of grain and 110 L.E. for ton of stalk.

Table 9. Comparison study among K fertilizer rates with foliar B concentration B_2 as relative increase (RI %) and economic evaluation for the increases in grain yield compare with control.

Treatments	Stalk yield (kg fed^{-1})	The increases in stalk yield (kg fed^{-1})	RI %	Grain yield (kg fed^{-1})	The increases in grain yield (kg fed^{-1})	RI %	Total cost of K and B applied (L.E)	Gross return (L.E) grain	stalk	Total	Net return (L.E)
Control	3808	0.0	0.0	2278	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_2	4618	810	21.26	2976	698	30.61	200	1396	89	1485	1285
$K_2 \times B_2$	5057	1249	32.80	3217	939	41.20	480	1878	137	2015	1535
$K_3 \times B_2$	5284	1476	38.77	3554	1276	55.98	620	2552	162	2714	2094
$K_4 \times B_2$	5369	1561	40.99	3700	1422	62.41	760	2844	172	3016	2256
$K_5 \times B_2$	4892	1084	28.46	3223	945	41.45	400	1890	119	2009	1609
$K_6 \times B_2$	5200	1392	36.53	3657	1379	60.53	680	2758	153	2911	2231

Control: K_0+B_0; B_2: foliar 50 mg B L^{-1}; K_2: 24 kg K_2O; K_3: 36 kg K_2O; K_4: 48 kg K_2O; K_5: foliar 2 % K_2O; K_6: 24 kg K_2O+ foliar 2 % K_2O

Data illustrate that the highest RI % for stalk yield (40.99 %) was at K-rate K_4, followed by K_3 (38.77%) and K_6 (36.53%). In additionally, the highest RI % for grain yield (62.41 %) was at K-rate K_4, followed by K_6 (60.53%) and K_3 (55.98%). For net return by Egyptian pound (L.E) of K fertilization rates, it is obvious that the highest net return K_4 (2256 L.E) followed by K_6 (2231 L.E) then K_3 (2094) with slight differences. So, these results illustrate that K fertilization at rate K_3 (36 kg K_2O fed^{-1}) or at K_6 (24 kg K_2O fed^{-1}+foliar 2% K_2O) with foliar B (50 mg B L^{-1}) was the maximum economic to achieve optimum maize grain yield under study conditions.

CONCLUSION

From the present study, it can be concluded that under Aswan Governorate conditions, K-fertilization at 24 kg K_2O fed^{-1}+foliar 2% K_2O or 36 kg K_2O Fed^{-1} with foliar boron at concentration of 50 mg B L^{-1} twice after 55 and 70 days from planting with addition the constant recommended doses of nitrogen (120 kg N fed^{-1}) and phosphorus (30 kg P_2O_5) achieve the optimum yield of maize crop with high quality.

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استجابة محصول الذرة الشامية الصفراء للتسميد بالبوتاسيوم والبورون تحت ظروف مصر العليا

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البوتاسيوم والبورون من المغذيات الضرورية لنمو النباتات وتنمية المحصول لدورهما كمنشطات للإنزيمات ودورهما في انتقال السكريات والكربوهيدرات حيث هناك علاقة تنشيط بينهما ، فالنباتات التي لها احتياجات كبيرة من البوتاسيوم تحتاج أيضا لمستويات من البورون في الأنسجة أكبر من 20 جزء في المليون لتحقيق التوازن معه، ولتحقيق أقصي محصول من الذرة فإن ذلك يتطلب التسميد بالبوتاسيوم والبورون معا ولاسيما في الأراضي التي يوضح اختبارها انخفاض مستوي البوتاسيوم والبورون الميسرين. لذا أجريت تجربتان حقليتان خلال موسمي الزراعة الصيفيين لعامي 2015 و 2016 بمحطة بحوث كوم امبو الزراعية- مركز البحوث الزراعية- محافظة أسوان – مصر (الواقعة بين خط عرض 24° - 47´ - 21.40" وخط طول 32° -92´ -47.50") لتقييم استجابة محصول الذرة الشامية الصفراء (هجين فرد 168- أصفر) لإضافة معدلات مختلفة من التسميد بالبوتاسي: K_1 (كنترول بدون تسميد)؛ K_2 (24 كجم K_2O للفدان)؛ K_3(36 كجم K_2O)؛ K_4 (48 كجم K_2O)؛ K_5 (رش 2% K_2O) و K_6 (24 كجم K_2O + رش 2% K_2O)؛ والرش بتركيزات مختلفة من البورون علي النباتات: B_0 (كنترول بدون رش)؛ B_1 (25 ملليجرام بورون /لتر) و B_2 (50 ملليجرام بورون /لتر). نفذت التجربة كقطع منشقة في ثلاث مكررات و تمثلت معاملات التسميد بالبوتاسيوم في القطع الرئيسية ومعاملات الرش بالبورون في القطع الشقية. أوضحت النتائج أهمية التسميد بالبوتاسيوم والبورون لمحصول الذرة الشامية وجودته تحت هذه الظروف، إذ أظهرت زيادة معنوية في محصول حبوب الذرة ومكوناته وجودته وتركيز عناصر النتروجين والفوسفور والبوتاسيوم والبورون والممتص منهم مع إضافة معدلات سماد البوتاسيوم المختلفة و الرش بالبورون، كما أدي التفاعل بين معدلات التسميد بالبوتاسيوم والرش بتركيزات البورون المختلفة إلي زيادة معنوية في محصولي حبوب وحطب الذرة ومحتوي الحبوب من الكربوهيدرات والزيت. سجل أعلي محصول من الحبوب (3700 كجم للفدان) ومن الحطب (5369 كجم للفدان) عند التفاعل بين معدل إضافة البوتاسيوم K_4 (48 كجم K_2O للفدان) والرش بالبورون B_2 (50 ملليجرام بورون في اللتر)، وذلك بدون فروق معنوية مع محصولي الحبوب والحطب المسجلة عند التفاعل بين K_3 و K_6 مع B_2، زاد تركيز عناصر النتروجين والفوسفور والبوتاسيوم والبورون والممتص منهم بواسطة محصولي الحبوب والحطب، بينما كانت هذه الزيادات معنوية فقط لتركيزي البوتاسيوم والبورون والممتص منهما. أوضح التقييم الاقتصادي أن التفاعل بين الرش بالبورون عند تركيز 50 ملليجرام بورون/لتر مع أي من معدلي التسميد البوتاسي K_6(24 كجم K_2O + رش 2% K_2O) أو K_3(36 كجم K_2O) كانتا الأفضل اقتصاديا مع تحقيق الإنتاجية المثلي لمحصول حبوب الذرة تحت ظروف الدراسة.