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Effect of Source and Rate of Potassium Fertilizer on Plant Growth Under Soil Water Stress

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Abstract

Two pot experiments were conducted to study the effects of soil water stress, and rate and type of K-fertilizer on some growth and physiological traits of two Maize (Zea mays L.) hybrids S.C.10 and T.W.C310. Three soil water regimes (100, 75 and 50% of soil field capacity), Three K application rates (0, 50, 100 kg K/fed.) and four types of K sources (KCl, K2SO4, KNO3 and a 1:1:1 mixture of them) were applied as the treatments of a split-split experimental design for each hybrid. The total chlorophyll a and b, fresh and dry weight were measured as growth parameters and leaf area ratio, net assimilation and relative growth rates were measured as physiological parameters. The obtained data indicated significant effects for moisture stress on fresh and dry weight of both S.C.10 and T.W.C.310 maize plants in the three growth stage and total chlorophyll content only in the third growth stage for both Maize hybrids. Potassium fertilization level effects were significant on the three characters in second and third growth stages in S.C.10 and in the first and second growth stages for fresh and dry weight besides the three growth stages for total chlorophyll content in T.W.C.310. However, potassium fertilizer source effects were significant on total chlorophyll content in the third growth stage, only for both maize hybrids. Potassium source had significant effect on fresh and dry weight in the three growth stages in S.C.10 and the first and second growth stages in T.W.C.310. Generally, non-water stressed treatment (100% of field capacity), the highest potassium level (45 kg/fed.) and potassium nitrate or sulphate produced the highest values of the tested traits. Increasing K application rate was found to relief the adverse effect of soil moisture stress on the two tested maize hybrids. Also, selection of suitable K source has a beneficial effect for better plant growth. Potassium nitrate produced the highest values of the most studied growth characters.

Keywords: *K-fertilizer, K application rate, Aerodynamics, soil moisture stress, soil water stress*

1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in the world. It ranks the third of the world cereal crops because it has a vital rule filling the food gab for human and animal. Although, maize production began in Libya several years ago but there is a gap between maize production and consumption particularly. Covering this gap can be achieved through improving all

the cultural practices starting from seed bed preparation to harvesting choosing the high yielding maize hybrids, as well as increasing maize cultivation area in the extension in the newly reclaimed in Sirt region such as Bishr, Al-Nufalyah and Kardabia (Sandy to sandy loam soils). Therefore, efforts should be focused on increasing productivity of this essential crop by growing new hybrids as single and three way crosses (S.C. and T.W.C) under the most favorable cultural treatments.
Because maize is very sensitive to water stress, irrigation and drought are the most important environmental factor limiting corn productivity in semiarid region in the world. Moreover, it remains the single most important factor threatening the food security of people in the developing world. Kramer (1963) surveyed water general functions in plants as follows: (a) It is the major constituent of physiologically active tissue. (b) It is a reagent in photosynthesis and in hydrolytic processes such as starch digestion. (c). It is the solvent in which salts, sugars and other solutes move from cell to cell and organ to another. (d). It is essential for the maintenance of the turgidity necessary for cell enlargement and growth.

Nomir (1994) showed significant differences between tested levels of soil moisture in respecting to leaf pigments, and reported that plant leaf pigments (chlorophyll a, b and carotenoids) concentration, were decreased with increasing soil moisture stress.
Moursi (1997), in Egypt, showed that chlorophyll a, b and carotenoids significantly differed among maize genotypes. He added that water stress at pre-tassling stage decreased the photosynthetic pigments by 15.8, 23.73 and 12.24% for chlorophyll a, b and carotenoids, respectively. Jurisic et. al. (1998) concluded that increasing water deficit from 93.9 to 142.7mm led to decrease maize grain yield from 7.320 to 5.591 t/ha, respectively.

Zhang et. al. (1998), in China, showed that the two halves of the root system were alternatively exposed to a drying soil and a soil with its water content maintained above 55 or 65% of its field capacity, the total biomass production was reduced by 6-100% compared to the well-watered plants. Fiechtinger and Scheidl (1999), in Austria, pointed out that various observations showed that inadequate soil water supply limits maize production in Austrian brown earth soils. Essa (2003), in Egypt, reported that severe water deficit resulted in lower biomass production and short plant height and there were differences among genotypes for leaf area and crop growth rate (C.G.R.). Andria et. al. (1997), in sandy clay soil at Italy, concluded that increasing irrigation numbers from non-irrigation (rainfed) to two, four or weekly irrigation for maize hybrid Aide gave gradual increases in leaf area index (L.A.I) and the highest L.A.I was obtained from irrigation weekly. Moursi (1997), in Egypt, indicated that reducing number of irrigation decreased ear leaf area in maize plants with reduction percentage of 6.99% and 12.97% in two seasons of study. Dunn and Fremmelt (1998) studied the effect of soil moisture on photosynthesis and water relations of maize and concluded that when soil moisture was withheld, photosynthesis and stomata conductance were significantly reduced. El-Ganayni (2000), in Egypt, revealed that

increasing irrigation intervals of maize "S.C.10" from 7 to 12, 17 and 22 days resulted in significant decrease in leaf area/plant. Irrigation every seven days gave the highest values of growth.
Debreczeni (1998), in Hungary, indicated the results of the National Long term Fertilization Trials Network, which cleared that Potassium fertilizers significantly increased maize yields grown on the calcareous soil, but had a much smaller effects on strongly acidic and brown forest soil with clay alleviation. Howard *et al.* (1998), in USA, reported that PK application to maize crop by rates of 15 : 28, 29 : 56, 44 : 89 and 59 : 112 kg/ha increased maize yield by 14%, compared to untreated treatment. El-Bana and Gomaa (2000), in Egypt, stated that there was significant increases in maize grain yield by 12.95 and 15.20% by increasing K levels from 25 to 50 and kg K_2O/fed., respectively.

Plants well supplied with K lost less water since K increased aromatic potential and had a positive influence on stomatal closure as well (Kramer, 1959; and Hale and Orcutt, 1987). The role of K in the cation-anion balance is also reflected in nitrate metabolism, in which K often is the predominant centurion for NO_3^- in long-distance transport as well as for storage in vacuoles (Aslam, 1975; Howard et. al., 1998). The role of K as the dominant counter ion to light-induced H^+ flax across the thylakoid membranes and the establishment of the transmembrane pH gradient necessary for the synthesis of ATP, in analogy to ATP synthesis in mitochondria was extensively studied (Garcia, 1983). With respect to potassium sources, many researchers indicated that some potassium sources are more favorable to uptake by specific plant species than others. Therefore, the main objectives of the present investigation were as follows:

1- Study the effect of soil water stress on maize plant growth and physiological traits of two maize hybrids S.C.10 and T.W.C310.
2- Study the effects of type and rate potassium fertilizer on the previous characters which of the two maize hybrids.

2. Materials and Methods

2. 1- Location:

The present study was conducted at the Faculty of Agriculture, Sirte.University, to study the effect of soil moisture content, potassium fertilizer levels and sources on plant growth, some physiological traits of maize (*Zea mays* L.).

2. 2 Soil:

A sandy soil sample was collected from the upper 30 cm soil surface from Al-Garadabia, at Sirte. A composite sample was collected from the upper 0.3m soil layer of a conventionally cropped field. The main soil physical and chemical properties are shown in Table (1).

2. 3 Experimental Layout:

Two pot experiments were carried out in the greenhouse for two maize cultivars including: single cross (S.C.10) and three way cross (T.W.C.310). Plastic pots (30 cm in diameter) were used in the two experiments. Each pot was uniformly filled with 10 kg air-dried soil leaving 5 cm. of free upper space for irrigation practice. Five grains were seeded on July, 24th and the seeding were thinned to 3 plants per pot after three weeks.

Before sowing, 1.5 g/pot super phosphate (15.5% P_2O_2) was incorporated with soil in each pot (225 kg P_2O_2/faddan), and ammonium nitrate (33.5% N) was added at a rate of 3.582 g/pot (120 kg N/fed.) in two equal doses (after thinning and 45 days from sowing). Four potassium sources (potassium chloride: 50% K, potassium sulfate: 42% K, potassium nitrate: 37% K and a mixture of 1:1:1 from the three forms: 43% K) were applied in a single dose after thinning (21 days after sowing) at different rates (0, 15, 30, 45 kg/feddan). In addition, three moisture regimes (watering to maintain the following % of field capacity) were applied.

The two experiments were laid out in a split-split plot design with three replicates. Moisture stress occupied the main plots, potassium rates were allocated to the subplots and potassium sources treatments occupied the sub-subplots.

Table (1). Some physical and chemical properties of the used soil.

Criteria	I. Values	Criteria	II. Values
III. Particle-size distribution:		IV. Soluble cations, meq/100	
V. Sand %	92.80	VI. Ca^{++}	0.27
Silt %	5.40	Mg^{++}	0.13
Clay %	VII. 1.80	Na^{+}	0.14
Texture class	VIII. Sandy soil	K^{+}	0.03
IX. Saturation percentage, %	16.00	X. Soluble Anions, meq/100g	
Field capacity, %	9.50	$CO^{-2}_3 + HCO^-_3$	0.37
Wilting point	2.50	Cl^-	0.20
EC (1:1 water extract), dS/m	0.30	SO_4^{-2}	0.12
pH (1:1 water suspension)	8.50	XI. Available nutrients, mg/kg	
Organic matter, %	0.15	N	20.00
$CaCO_3$ %	3.58	P	5.00
XII.		K	40.00

2. 4 Sampling and Analyses:

Both soil and plant samples (each of a plant/pot) were collected in triplicates after 45, 60 and 75 days from sowing at the 1st, 2nd and 3rd growth stages, respectively. The three soil samples were taken for chemical analysis. Before sampling, total chlorophyll content was digital determined using Chlorophyll meter (SPRD-502). At each harvest, the fresh weight yield per pot recorded, washed with distilled water, oven dried at (65°C) to obtain dry weight and ground to pass through 40 mesh screen and digestion for nutrient contents determination.

Various plant growth traits were determined for both SC10 and TWC310 cultivars. These included:
1- Total chlorophyll content (mg/ gm): was determined just before taken each of the three samples by using chlorophyll meter (SPAD-502). Reported by Minolta Camera Co. (1989).
2- Fresh weight (gm): After taking the sample and washing its roots with distilled water the whole plant weighed in grams.
3- Dry weight (gm): After oven dried the sample at 65°C for 48 hours it weighed in grams.
In addition, three physiological were calculated according to the following formula according to Radford (1967) as follows:

1. Leaf area ratio (L.A.R.) desi.^{2}/gm = $$\frac{(\log_e W_2 - \log_e W_1)}{(\log_e A_2 - \log_e A_1)} \cdot \frac{(A_2 - A_1)}{(W_2 - W_1)}$$

2. Net assimilation rate (N.A.R.) gm/m^2/week = $$\frac{(W_2 - W_1)}{(A_2 - A_1)} \cdot \frac{(\log_e A_2 - \log_e A_1)}{(t_2 - t_1)}$$

3. Relative growth rate (R.G.R.) gm/gm/week = $$\frac{(\log_e W_2 - \log_e W_1)}{(t_2 - t_1)}$$

Where W_1, A_1 and W_2, A_2, respectively refereed to dry weight and leaf area at time t_1 and t_2 in weeks.

2. 5 Statistical analysis:

Recorded data were statistically analyzed for ANOVA and L.S.D. values were calculated to test the differences between of the studied treatments according to Steel and Torrie (1980).

3. Results And Discussion

A. Growth Characters:
1. Total Chlorophyll Content:

Total chlorophyll content as affected by the main effects of water stress, potassium fertilizer levels and sources in the three plant ages three plant stages (45, 60 and 75 days after sowing) were illustrated in Table (2). Generally total chlorophyll content significantly increased with increasing potassium fertilization up to 45 kg/fed. compared to the check treatment in the three growth stages, respectively.

Increasing water stress from 100 to 50% of water field capacity decreased total chlorophyll content by 9.3, 4.5 and 4.5% in the three growth stages, respectively. Water stress had significant effect only in the third growth stage where the total chlorophyll content was statistically equaled at 100 and 75% of water field (75 days after sowing) capacity and surpassed on 50% water field capacity. That might be due to greates plant size and then increasing the evapotranspiration rate in that stage (an thesis), where water is a reagent in photosynthesis (Kramer, 1963). Similar results were obtained by El-Zainy (1981), Ragab *et al.* (1986), Nomir (1994), Moursi (1997), Gutierrez-Rodriguez *et al.* (1998).

As for potassium fertilizer levels, data presented in (Table 2) showed that increasing potassium from 0.00 rates up to 45 kg K/fed. increased total chlorophyll content by 2.33, 3.46 and 3.41 mg/gm, in the three harvest dates. Increasing potassium rates did not affected the total chlorophyll content in the first growth stage. But in the second growth stage, potassium application by any of the three levels, i.e., 15, 30 or 45 kg/fed had the same significance level compared to the check treatment (control). On the other hand, in the third growth stage, 45 or 30 kg K/fed. produced the highest total chlorophyll contents (22.53 and 21.74 mg/gm).

With respect to potassium fertilizer sources, there were no significant differences between the studied sources on total chlorophyll content in at the first and second harvest dates of maize. However, chloride form surpassed the other three forms of potassium for total chlorophyll content in the third growth stage (22.62 mg/gm), and there were no statistically differences between the other potassium sources (sulphate, nitrate and the mixture). This could be explained on the basis that chloride anion has more fast absorption than the other sources (Kochian and Lucas, 1988). Also, chloride influences the plant's water relations and has no effect on metabolism (Von Braunscheig, 1986).

Table (2). Means of total chlorophyll content (mg/gm) of S.C.10 and T.W.C.310 maize hybrids plants in the three growth stages@.

Treatments	S.C.10			T.W.C310		
	1st stage	2nd stage	3rd stage	1st stage	2nd stage	3rd stage
Water stress (% of Field capacity)						
100	21.34	19.34	21.41 a	21.10	20.38	34.11 a
75	19.38	19.26	21.19 a	17.70	16.59	21.68 b
50	19.35	18.47	20.45 b	18.73	16.32	19.11 b
$L.S.D._{0.05}$	--	--	0.57	--	--	3.37
K-rates (kg/fed.)						
0	19.08	17.03 b	19.12 c	18.25 b	17.62 b	22.54 b
15	19.13	18.89 a	20.67 b	18.90 ab	17.16 b	25.86 a
30	20.49	19.41 a	21.74 ab	18.83 ab	17.21 b	25.64 a
45	21.41	20.49 a	22.53 a	20.73 a	19.06 a	25.80 a
$L.S.D._{0.05}$	--	1.59	1.52	1.74	1.20	1.80
XIII. K-sources						
XIV. KCl	21.15	19.54	22.62 a	19.96	18.89	25.15 ab
K_2SO_4	18.75	18.83	21.19 b	20.29	18.16	23.98 b
KNO_3	20.75	18.94	20.20 b	18.71	17.27	25.88 a
1:1:1	19.44	18.54	20.05 b	17.75	16.73	24.84 ab
$L.S.D._{0.05}$	--	--	1.34	--	--	1.29

*Means followed by the same letter (s) are not significantly different according to $L.S.D._{0.05}$
@ 1st, 2nd, 3rd stages represent the first, second and third harvests on the plants aged 45, 60 and 75 days old, respectively.

For T.W.C.310, the same trend in total chlorophyll content was observed where that trait was significantly affected by water stress and potassium fertilizer sources only in the third growth stage and both of potassium rates and water stress x potassium fertilizer levels in the three growth stages. However, other two and three factor interactions did not reach the significance level (Table 2).

Means of total chlorophyll content of T.W.C.310 under the three studied factors, i.e., water stress, potassium fertilizer rates and sources effects during the three growth stages were presented in Table (2). Data in that table showed that increasing water stress up to 50% of water field capacity decreased total chlorophyll content by 11.2, 19.9 and 44.0% compared to unstressed treatment (100% of water field capacity) in the three successive growth stages. Several authors have reported decreases in total chlorophyll content under water stress condition (Maranvill and Paulsen, 1970; Albert *et al.*, 1977; El-Zainy, 1981; Nomir, 1994; Moursi, 1997 and Gutierrez-Rodriguez *et al.*, 1998). According to Virgin (1965), the pigment formation mechanism localized to the chloroplasts is sensitive to the changes in water content whereas the photochemical transformation of protochlorophyll to chlorophyll is little influenced. There are some indication revealing the effect of water stress on chlorophyll content may be attributed to the disturbance of chlorophyll synthesis rather than its destruction.

With respect to water stress x potassium levels interactions at the three harvest dates, showed that, in the three growth stages, any of the four potassium levels under adequate water (100% of water field capacity) produced the highest total chlorophyll content, however potassium application by the rate of 15 kg/fed. under 50% of water field capacity, 45 and 30 kg/fed under 75% water field capacity in the three successive growth stages produced 20.65, 19.00 and 24.00 mg chlorophyll/g, respectively. Reduction for total chlorophyll content which showed under water stress (50% and partially 75% of water field capacity) at any potassium level indicated that chlorophyll content is more sensitive to changes in water content than potassium fertilizer rates (Virgin, 1965; Nussell and Staples, 1979). This holds true, because potassium application increased water use efficiency especially under non stressed maize plants (Mottram, 1985; Premachandra et. al., 1991). The last researcher added that water stressed plants imposed greater adaptation to water deficits at higher potassium fertilizer levels.

2. Fresh Weight:

Means of S.C.10 plant fresh weight under the three studied factors, i.e., water stress, potassium fertilizer levels and sources effects in the three growth stages were presented in Table (3). With regard to water stress, increasing water deficit from M1 (100%) to M3 (50%) of water field capacity, fresh weight of S.C.10 maize plant significantly decreased from 21.00 to 15.80; 53.01 to 35.07 and 160.81 to 120.11 gm in the three growth stages, respectively. However, plant fresh weights were statistically equaled at both M1 (100%) and M2 (75%) of water field capacity in the three growth stages. Similar findings were obtained by many workers such as El-Maghraby (1966), Musick and Dusek (1980), El-Sheikh (1994), Jurisic et al. (1998), Gencoglan and Yazar (1999), and Essa (2003) who reported that water is essential for the maintenance of turgidity necessary for all enlargement and growth.

Concerning to potassium fertilizer rates, the data in Table (3) showed that successive potassium application up to 45 kg/fed. Generally, increased maize plant fresh weight in the three studied growth stages, however, this increase was not significant in the first growth stage (45 days after sowing). In the second growth stage (60 days after sowing), 30 and 45 kg K/fed produced the heaviest fresh weights (52.07 and 54.91 gm) followed by 15 kg K/fed (43.15 gm) and untreated plants with potassium were the lightest weight (37.76 gm). On the other hand, in the third growth stage (75 days after sowing) 45 K/fed. produced the heaviest plant fresh weight (167.19 gm) and there were insignificant differences between the other three potassium rates (0, 15 and 30 kg/fed), where plant fresh weights were 123.48; 143.05 and 142.20 gm, respectively. These results were in general agreed with those obtained by Ibrahim (1982), Ogunlela and Yusuf (1988), Bar-Tal et al.

(1991), Marsh and Pierzynski (1998), and El-Bana and Gomaa (2000). Conversely, Hamissa et al. (1975). Santhy et al. (1998) and Ning and Dai (1999) concluded that potassium fertilizer levels did not affected in maize plant weight. With respect to potassium sources effect on S.C.10 maize plant fresh weight, potassium nitrate produced the heaviest plant weight in the first and third growth stages (22.04 and 165.90 gm), respectively. However, potassium sulphate, nitrate and the mixture of the two mentioned forms beside chloride by equal share produced heavier plant fresh weight (50.41, 48.30 and 46.94 gm) than potassium chloride (42.25 gm) in the second growth stage. Miley and Oosterhius (1994) and Howard et al. (1998) indicated that potassium nitrate increased plant weight and yield compared to potassium sulphate, carbonate and chloride.

Table (3). Means of plant fresh weight (gm) of S.C.10 and T.W.C.310 maize hybrids plants in the three growth stages@.

Treatments	S.C.10			T.W.C.310		
	1^{st} stage	2^{nd} stage	3^{rd} stage	1^{st} stage	2^{nd} stage	3^{rd} stage
Water stress (% of field capacity)						
100	21.00 a	53.01 a	160.81 a	22.00 a	60.12 a	420.25 a
75	20.63 a	52.84 a	151.02 a	16.56 b	40.51 b	177.51 b
50	15.80 b	35.07 b	120.11 b	12.32 c	31.57 b	89.54 b
$L.S.D._{0.05}$	3.55	7.94	17.10	2.31	9.68	95.74
K-rates (kg/fed.)						
0	20.84	37.76 c	123.48 b	13.41 b	36.81 b	169.86
15	16.58	43.15 b	143.05 b	15.78 b	41.79 b	204.60
30	19.00	52.07 a	142.20 b	16.06 b	46.89 ab	241.22
45	20.16	54.91 a	167.19 a	22.59 a	50.77 a	300.72
$L.S.D._{0.05}$	--	5.36	19.76	2.29	6.02	--
1) K-sources						
(a	18.61 b	42.25 b	142.85 b	18.33 a	46.34 a	207.71
K_2SO_4	18.72 b	50.41 a	126.44 b	17.67 ab	45.33 a	195.16
KNO_3	22.04 a	48.30 ab	165.90 a	15.99 ab	45.56 a	325.45
1:1:1	17.21 b	46.94 ab	140.73 b	15.84 b	39.04 b	188.07
$L.S.D._{0.05}$	2.14	5.65	17.67	2.48	5.80	--

*Means followed by the same letter (s) are not significantly different according to $L.S.D._{0.05}$

@ 1^{st}, 2^{nd}, 3^{rd} stages represent the first, second and third harvests on the plants aged 45, 60 and 75 days

old, respectively.

Water stress x potassium fertilization levels interactions had a significant effects on S.C.10 maize plant fresh weight in the second and third growth stages. Potassium application, in general, produced the heaviest plants under adequate moisture treatment (100% of water field capacity) followed by higher potassium application rates (45 kg/fed.) under moderate stress treatment M2 (75% field capacity in both growth stages and high stress treatment M3 (50% field capacity) in the third growth stage. In the contrast, the lightest plant fresh weights resulted under the highest moisture stress M3 (50% of field capacity) without potassium application. However, moderate plant fresh weight resulted under M3 (75% of water field capacity) without potassium fertilization in both growth stages. Previous results indicated that water stress plants showed great adaptation to water deficits at higher potassium levels and this might be due to the effect of high potassium rates to reduce the adverse effects of water stress on the photosynthetic rate (Dekov and Velichkov, 1992). Yapa et. al. (1991) added that high. The analysis of variance showed that both water stress and potassium fertilizer sources in the three growth stages and potassium levels only in the second and third growth stage of S.C.10 had significant effects on fresh weight in that maize cross. With regard to first and second order interactions, only water stress x potassium level interactions had significant effects on plant fresh weight in the second and third growth stages, however, other first and second order interactions had insignificant effects on that trait in S.C.10 in the three growth stages.

With regard to T.W.C.310 corn plant fresh weight, Table (5) show that water stress had significant effects on plant fresh weight in the three studied growth stages, however, potassium fertilizer rates and sources besides the water stress x potassium levels interactions had significant effects on that trait in the first and second growth stages. Conversely, other two and three factors interactions did not reach the significance level. These results pointed out that there were significant differences between the two studied maize crosses, i.e., S.C.10 and T.W.C.310 in their responses to the factors under study and this confirmed with Kamel et al. (1986). As for water stress, means of T.W.C.310 plant fresh weight in Table (3) showed that increasing water stress from M1 (100%) to M3 (50%) of water field capacity led to significant decreasing in plant fresh weight from 22.00 to 12.32; 60.12 to 31.57 and 420.25 to 89.54, respectively, in the three growth stages. However, T.W.C.310 plant fresh weights were insignificantly differed between M2 (75%) and M3 (50%) of water field capacity in the second and third growth stages. This mean that T.W.C.310 is more drought tolerant than S.C.10 and these differences in response of each cross to water stress could be attributed to genetical factors which were reflected on growth characteristics (Kamel et al., 1986). Many researchers reported that increasing water stress led to decrease in fresh weight such as Mederisk and Wilson, (1960), Abou-Ellil, (1992), Mokadem and Salem (1994), Mapfumo et. al., (1998), Yang and Chen, (1998) and Fiechtinger and Scheidl, (1999).

With respect to potassium fertilization levels effect, data presented in (Table 3) showed that T.W.C. 310 plants significantly responded to higher potassium levels (45 kg/fed. in the first and 30 and 45 kg/fed. in the second growth stages), but the response was insignificant in the third growth stage. Increase percentages in plant fresh weight at 30 and 45 kg k/fed were19.8, 68.5, 27.4, 37.9; 42.0 and 77.0 in the three successive growth stages as compared to check treatment. These increases might be due to the importance of potassium role in carbohydrate metabolism and starch translocation in plants (Woodruf et. al., 1987). These results are in general agreement with those obtained by Sweeney (1989), Bar-Tal et. al. (1991), and Aly et. al. (1999). On the contrary, Hamissa et. al. (1975), Santhy et. al. (1998) and Ning et. al. (1999) pointed that potassium fertilization did not significantly affect maize plant weight.

With respect to potassium fertilizer sources, data presented in (Table 3) showed that any of the three studied potassium forms (chloride, sulphate and nitrate) produced the heaviest plant fresh weights (18.33, 17.67, 15.99; 46.34, 45.33, 45.56; 207.71, 195.16, 325.45 gm), respectively, in the three growth stages. Conversely, mixture of the three mentioned forms produced the lightest plant weights (15.84, 39.04 and 188.07 gm) in the three successive growth stages. These findings are in general agreed with those obtained by Mullins and Barmester (1995) who pointed out that there were no differences between K_2SO_4, $K_2S_2O_3$, KCl and KNO_3 on yield and Howard et al. (1998) who reported that all mentioned potassium sources led to increase the biological yield.
Concerning to water stress x potassium fertilizer levels interaction effects on maize T.W.C.310 plants fresh weight showed that 45 kg K/fed in the first growth stage and both 15 or 45 kg K/fed in the second growth stage under adequate water (M1) 100% of water field capacity produced the highest plant fresh weights (31.79, 73.91 and 64.23 gm), respectively. Conversely, moderate and higher water stress M2 and M3 (75 and 50% of water field capacity) gave the lowest plant fresh weights under without potassium application (check treatment). On the other hand, potassium application under moderate water stress (M2) produced intermediate fresh weights in the second growth stage (40.24, 44.34 and 51.12 gm) under 15, 30 and 45 Kg K/fed., respectively. These results indicate that potassium application could overcome the deleterious effects of soil moisture (Yapa et. al., 1991) and reduce the adverse effects of inadequate moisture on the photosynthetic rate (Dekov and Velichkov, 1992). These results were in general agreed with those obtained by Mottram (1985), Faizy et al. (1986), and Li et al. (1996).

3. Dry Weight:

Mean squares of the analysis of variance showed that water stress and potassium fertilization sources in the three growth stages and potassium levels in the second and third growth stages had significant effects on S.C.10 maize plant dry weight. Only water stress X potassium application rates had significant effects on that trait in the second and third growth stages, however other two and three factor interactions did not have significant effects on plant dry weight in S.C.10 hybrid. Means of plant dry weight in S.C.10 maize hybrid under the three studied factors, i.e., water stress, potassium fertilization rates and sources effects in the three growth stages were presented in (Table 3). Increasing water stress from M1 (100% of water field capacity) to M3 (50% of water field capacity) led decreasing plant dry weight in S.C10 maize hybrid during the three growth stages. Plant dry weights under adequate soil moisture (M1) were 8.84, 25.42 and 96.41 gm, however, these weights were 6.68, 18.86 and 54.72 gm, respectively, M3 soil moisture in the three growth stages. On the other side, plant dry weights under moderate water stress (75% of water field capacity) were 7.70, 22.00 and 76.29 gm in the three growth stages, respectively. These results could be due to the function of water as a reagent in photosynthesis and in hydrolytic processes such as a starch digestion (Kramer, 1963). Similar results obtained by Va'Clavik (1967), Robertson and Lurdy (1973), Ainer (1976), Kolev et. al. (1998), Gencoglan and Yazar (1999) and Essa (2003).

With regard to potassium fertilization, the highest level (45 kg/fed) produced the heaviest plant dry weights (26.72 and 81.73 gm) in the second and third growth stages. Conversely, check treatment (unfertilized) produced the lightest plant dry weights (16.11 and 67.96 gm) in the two successive growth stages. Intermediate potassium fertilizer levels (15 and 30 kg/fed) produced intermediate dry weights in the second and third growth stages. These results might be due to the significance role of potassium in carbohydrate metabolism and translocation in plants. Ogunlela and Yusuf (1988), Sweeney (1989), Bar-Tal et. al. (1991), Debreczeni (1998), Aly et. al. (1999) and El-Bana and Gomaa (2000) found similar results. In connection to potassium fertilization sources, nitrate form produced the maximum plant dry weights (8.49, 24.24 and 91.78 gm), respectively, in the three growth stages followed the mixture of chloride, sulphate and nitrate forms (7.43, 17.86 and 78.43 gm) in the three growth stages and chloride form (7.71, 24.96 and 71.60 gm) in the three growth stages. Miley and Oosterhius (1994) reported that nitrate form increased growth and yield. These results were agreed with those obtained by Howard et al. (1998) and Mohamed (1998).

Table (3). Means of plant dry weight (gm) of S.C.10 and T.W.C.310 maize hybrids plants in the three growth stages@.

Treatments	S.C.10			T.W.C.310		
	1st stage	2nd stage	3rd stage	1st stage	2nd stage	3rd stage
Water stress (% of field capacity)						
100	21.00 a	53.01 a	160.81 a	22.00 a	60.12 a	420.25 a
75	20.63 a	52.84 a	151.02 a	16.56 b	40.51 b	177.51 b
50	15.80 b	35.07 b	120.11 b	12.32 c	31.57 b	89.54 b
L.S.D.$_{0.05}$	3.55	7.94	17.10	2.31	9.68	95.74
K-rates (kg/fed.)						
0	20.84	37.76 c	123.48 b	13.41 b	36.81 b	169.86
15	16.58	43.15 b	143.05 b	15.78 b	41.79 b	204.60
30	19.00	52.07 a	142.20 b	16.06 b	46.89 ab	241.22
45	20.16	54.91 a	167.19 a	22.59 a	50.77 a	300.72
L.S.D.$_{0.05}$	--	5.36	19.76	2.29	6.02	--
1) K-sources						
(a	18.61 b	42.25 b	142.85 b	18.33 a	46.34 a	207.71
K_2SO_4	18.72 b	50.41 a	126.44 b	17.67 ab	45.33 a	195.16
KNO_3	22.04 a	48.30 ab	165.90 a	15.99 ab	45.56 a	325.45
1:1:1	17.21 b	46.94 ab	140.73 b	15.84 b	39.04 b	188.07
L.S.D.$_{0.05}$	2.14	5.65	17.67	2.48	5.80	--

* Means followed by the same letter (s) are not significantly different according to L.S.D.$_{0.05}$
@ 1st, 2nd, 3rd stages represent the first, second and third harvests on the plants aged 45, 60 and 75 days old, respectively.

With respect to water stress x potassium fertilization levels interaction in the second or third growth stage, application of 45 kg k/fed. under non-stressed plants produced the heaviest dry weights (31.37 and 108.62 gm) in the second and third growth stages in S.C.10 hybrid. In the contrary, stressed plants under 50% of water field capacity under without potassium application gave the lowest dry weight plants (14.58 and 38.73 gm) in the second and third growth stages, respectively. On the other hand, potassium fertilizer application to moisture stressed plants (75 and 50% of water field capacity) decreased the adverse effects of drought on plant dry weight. Increasing percentages in plant dry weight under 50% water field capacity in the second growth stage were 28.4, 21.5 and 67.6%, respectively, under K fertilizer levels (15, 30 and 45 kg /fed.) compared to non K fertilization treatment. However, these increasing percentages were 50.6, 57.4 and 27.2%, respectively, in the third growth stage. These results showed the importance effect of potassium, for compensation of inadequate soil moisture, on plant growth (Yapa et al., 1991 and

DeKov and Velichkov, 1992). These findings are in agreement with those obtained by Mottram (1985), Premachandra et al. (1991) and Li et al. (1996).

As for T.W.C.310 hybrid, mean squares of the analysis of variance of plant dry weight showed that water stress had significant effects on that trait in the three growth stage while both potassium fertilizer levels and sources had significant effects in the first and second order interactions, only water stress x potassium rates had significant effects on plant dry weight in the first and second growth stages.

Means of plant dry weight as affected by the three studied factors, i.e., three water stress, four potassium fertilizer levels and four potassium fertilizer sources during the three growth stages were illustrated in Table (3). Increasing moisture stress from 100 to 75% of water field capacity decreased plant dry weights by 25.7, 41.9 and 47.45%, respectively, in the three growth stages. However, increasing water stress up to 50% of water field capacity decreased plant dry weights by 34.8, 59.6 and 78.2% in the three successive growth stages compared to the unstressed plants (100% of water field capacity). Similar results were obtained by El-Maghraby (1966), Va'Clavik (1967), Ainer (1976), Musick and Dusek (1980), El-Sheikh (1994), Kolev et. al. (1998), Rafailov et. al. (1998), Tolk et. al. (1998), Fiechtinger and Scheidl (1999) and Essa (2003).

Data in Table (3) showed that increasing potassium rates from 0 to 45 kg K/fed. gradually increased plant dry weights, however,, these increases did not reach the significance level in the third growth stage. The highest potassium level (45 kg/fed.) produced the heaviest dry weights (8.99, 21.80 and 100.97 gm) in the three growth stages, respectively, however, differences in dry weights between 0, 15 and 30 kg K/fed. in the first and second growth stages were insignificant. Woodruff et. al. (1987) referred plant dry weight increases under higher potassium fertilization rates to the essential role of potassium in carbohydrate metabolism and starch translocation in plants. Many researcher reported similar results such as Ibrahim et. al. (1989), Sweeney (1989 and 1993), Debreczeni (1998), Aly et. al. (1999) and El-Bana and Gomaa (2000). On the other hand, Hamissa et al. (1975), Santhy et. al. (1998) and Ning et. al. (1999) indicated that potassium fertilization did not have significant effects on maize plant dry weight. With respect to potassium fertilizer sources, both nitrate and chloride potassium sources produced the heaviest dry weight maize plants (8.76, 7.87; 18.11, 18.60, 91.37 and 90.50 gm) for the two forms in the three growth stages, respectively. However, the differences between the studied forms were insignificant in the third growth stage.

Statistical analysis revealed that the effect of water stress x potassium levels interactions on dry weights of T.W.C. 310 maize plants of the three growing first and second growth stages. The highest potassium fertilizer level (45 kg/fed.) under adequate moisture produced the highest plant dry weights (10.89 and 34.22 gm) in the first and second growth stages, respectively. However, 45 kg K/fed. application under moderate water stress (75% of field capacity) produced intermediate dry weights per plant in the first and second growth stages (8.70 and 19.68 gm). Conversely, non-potassium fertilization or low potassium fertilizer level (15 kg/fed.) under M2 or M3 water stress treatments produced the lightest dry weight plants in both growth stages. On the other side, 45 kg K/fed. under the higher water stress (50% of field capacity) decreased the adverse effects of water deficit on plant growth, where plant dry weights were 7.38 and 11.50 gm, respectively, in the first and second growth stages. Increasing potassium rate under adequate water produced higher dry matter than under water stress at various growth stages. This might be due to increasing water use efficiency with increasing potassium fertilizer rate and tended to be higher with non-stressed than stressed maize plants. Also, maize plants well supplied with potassium responded to water stress by immediate stomatal closure, whereas closure in potassium deficient plants was slow and inefficient.

B. Physiological parameters:

1. Leaf Area Ratio (L.A.R.):

The analysis of variance showed that potassium fertilization levels and had significant effects on leaf area ratio (L.A.R.) calculated in the second and third growth stages of S.C.10 maize plants, but soil water stress had significant effects at second growth stage only. On the contrary, any of potassium fertilization forms, first and second order interactions did not reach significance level.

Means of (L.A.R.) calculated in the second and third growth stages under the three studied factors, i.e., soil water stress, potassium fertilization rates and forms were presented in (Table 4). With regard to soil water stress effect, L.A.R. significantly decreased with increasing soil water stress below 75% of field capacity in the second growth stage. However, the differences between the three soil moisture stress did not reach significance level in the third growth stage, but the same trend was cleared. Unstressed water treatment (100% of field capacity) produced the largest leaf area ratio (1.075 and 1.127 desi.^{2}/gm), however the highest water stress (50% of field capacity) produced the smallest L.A.R. (0.946 and 1.026 desi.^{2}/gm) in S.C. 10 maize plants calculated in the second and third growth stages, respectively. These results could be due to the effect of soil water deficiency on increasing the pigments in leaf plastids and photochemical activity of leaf tissue homogenates and decreasing plant productivity (Tkachuk, 1971). Many researchers reported that increasing soil water stress led to decrease in L.A.R. such as Ainer (1976), Moursi et. al. (1983), Shahin (1985), Porro and Cassel (1986), Kheiralla et. al. (1989), Hefni et. al. (1993) Moursi (1997), Ibrahim (1998) and Hassan and Gaballah (1999).

As for potassium fertilization levels effect on (L.A.R.) data presented in Table (4) indicated that increasing potassium levels up to 45 kg/fed significantly increased (L.A.R.) calculated in the second and third growth stages. In the second growth stage, both 30 and 45 kg/fed. produced the largest L.A.R. (1.0106 and 1.113 desi2/gm), while both zero and 15 kg/fed produced the lowest L.A.R. (0.921 and 0.928 desi2/gm), respectively. On the other hand, only 45 kg/fed. produced larger L.A.R. (1.321 desi2/gm) than 0, 15 and 30 kg K/fed. (0.995, 0.949 and 1.030 desi^2/gm), respectively. These results agreed with those obtained by Vilela and Bull (1999). With regard to potassium fertilization form effects, the four studied forms did not have significant effects on leaf area ratio (L.A.R.). Mullins and Barmester (1995) obtained similar results. In case of T.W.C. 310 maize hybrid, mean squares of the analysis of variance of leaf area ratio showed that potassium fertilization levels had significant effects on L.A.R. In both second and third growth stages, respectively. However, either soil water stress, potassium fertilization sources or all two and three factor interactions did not have significant effects on that trait.

Table (4). Means of leaf area ratio ($desi^2/gm$) of S.C.10 and T.W.C.310 maize hybrids plants in the second and third growth stages[@].

Treatments	S.C.10			T.W.C.310		
	1st stage	2nd stage	3rd stage	1st stage	2nd stage	3rd stage
Water stress (% field capacity)						
100	8.84 a	25.42 a	96.41 a	9.25 a	25.53 a	150.20 a
75	7.70 b	22.00 ab	76.29 b	6.87 b	14.83 b	78.93 b
50	6.68 c	18.86 b	54.72 c	6.03 c	10.31 c	32.75 c
$L.S.D._{0.05}$	0.64	4.14	16.24	0.81	0.87	34.65
K-rates (kg/fed.)						
0	7.76	16.11 c	67.96 b	6.65 b	14.28 b	69.00
15	7.78	23.08 b	78.27 ab	6.92 b	14.54 b	82.65
30	7.76	22.45 b	75.25 ab	6.98 b	16.94 b	96.55
45	7.66	26.72 a	81.73 a	8.99 a	21.80 a	100.97
$L.S.D._{0.05}$	--	2.54	9.32	0.77	4.48	--
XV. K-Sources						
XVI. KCl	7.43 b	17.86 c	78.43 b	7.87 ab	18.60 a	90.50
K_2SO_4	7.33 b	21.31 b	61.41 c	7.35 b	16.03 b	86.12
KNO_3	8.49 a	24.24 a	91.78 a	8.76 a	18.11 a	91.37
1:1:1	7.71 ab	24.96 a	71.60 b	5.56 c	14.82 b	81.19
$L.S.D._{0.05}$	0.89	2.83	9.62	0.92	2.37	--

@ 1st, 2nd, 3rd stages represent the first, second and third harvests on the plants aged 45, 60 and 75 days old, respectively.

Means of leaf area ratio (L.A.R.) of T.W.C.310 hybrid under the three factors under study, i.e., soil water stress, potassium fertilization levels and forms during the second and third growth stages were illustrated in Table (4). Data in that table showed that adequate soil moisture content (100% of field capacity) significantly surpassed the other two water stresses (75% and 50% of field capacity) in the third growth stage. However, the differences between the three soil moisture contents did not reach the significance level in the second growth stages. The largest leaf area ratio (1.281 and 1.591 $desi^2/gm$) produced under favorable soil moisture content (100% of field capacity in the second and third growth stages. In the contrast, the smallest L.A.R. resulted under highest moisture stress (50% of field capacity) in the second and third growth stages (1.036 and

1.143 desi2/gm), respectively. Moderate soil water stress (75% of field capacity) produced intermediate L.A.R. values (1.268 and 1.450 desi2/gm), respectively, in the second and third growth stages. Results were agreement with those obtained by Ainer (1983), Refay (1989), Ibrahim et. al. (1992), Wery et. al. (1994), El-Marsafawy (1995), Atta Allah (1996), Andria et. al. (1997), Tolk et. al. (1998), Yang and Chem (1998) and Essa (2003).

As for potassium fertilization levels effect on L.A.R., increasing potassium rates up to 30 and or 45 kg/fed. significantly increased leaf area ratio calculated in the second and third growth stages, respectively. Similar results were obtained by Vilela and Bull (1999). With respect to potassium fertilization source effects, any of the four studied potassium sources did not have significant effects on leaf area ratio. These results agreed with those obtained by Mullins and Barmester (1995).

2. Net Assimilation Ratio (N.A.R.):

The analysis of variance, in the second and third growth stages of S.C.10 maize hybrid, indicated that net assimilation rate (N.A.R.) were significantly affected by potassium fertilization source and soil water stress in the second and third growth stages, respectively, and both of potassium fertilization rate and water stress X potassium rate interactions in both growth stages. Other two and three factor interactions had no significant effects on that trait.

Net assimilation ratio (N.A.R.) means at the second and third growth stages under soil moisture stress, potassium fertilizer levels and forms were illustrated in (Table 5). As for soil moisture stress, gradually decreasing in N.A.R. values with increasing soil water stress from 100 to 50% of field capacity in both second and third growth stages, however differences between N.A.R. values did not reach the significance level in the second growth stage. Net assimilation rate values were 29.63, 35.33, 28.88, 33.15 and 27.23, 22.20 gm/m2/week in the second and third growth stages at 100, 75 and 50% of field capacity, respectively. Decreasing N.A.R. with increasing soil water stress might be due to reduction the hill reaction activity of the chloroplasts (Fry, 1970) and increasing the pigments in the leaf plastids and photo chemical activity of leaf tissue homogenates and decreasing plant productivity (Tkachuk, 1971). On the other hand, Dekov and Velichkov (1992) added that water stress caused ultrastructural damage to chloroplasts and reduced photosynthetic rate and photochemical activity in maize plants. Similar results obtained by Porro and Cassel (1986), Hale and Orcutt (1987) Rizk et. al. (1987) and Dunn and Frommelt (1998).

With regard to potassium fertilizer levels effect, increasing potassium rate up to 30 or 45 kg/fed. led to significant increases in N.A.R. compared to 0 or 15 kg/fed. in the second and third growth stages of S.C. 10 cultivar. Net assimilation rate values at 30 and 45 kg K/fed. were 29.70, 33.47 and 33.40 and 33.02 gm/m2/week, respectively, in the second and third growth stages. On the contrary, these values were 24.00, 24.15 and 26.10 and 28.40 gm/ m2/week at zero and 15 kg/fed. in the second and third growth stages of S.C.10 cultivar, respectively. These results could be attributed to potassium effects on one or more of the following physiological functions: (a) Carbohydrate metabolism or formation breakdown and translocation of starch (b) Control and regulation of activities of various essential elements and (c) Activation of various enzymes (Ibrahim, 1982).

Regarding to the effect of potassium fertilizer form effects on N.A.R., potassium sulphate and nitrate produced the highest N.A.R. (35.10 and 37.80 gm/ m2/week and (31.88 and 31.05 gm/ m2/week) in the second and third growth stages, respectively. However, the differences in N.A.R. values did not reach the significance level in the third growth stage according to potassium forms. These results might be due to the effect of sulphate anion on soil pH decreasing and increasing absorption ability of the microelements. On the other hand, nitrate anion is considered of nitrogen source which increase the rate of carbohydrate formation. With regard to the effect of water stress x potassium fertilizer rate interactions on N.A.R. in S.C.10 maize plants potassium fertilization especially at higher levels i.e., 30 or 45 kg K/fed produced higher N.A.R. values at any of the three water stress in the second and third growth stages except at the most severe stress (50% of field capacity) in the third growth stage. These results could be due to reducing the adverse effects of water stress on chlorophyll a and b, photosynthetic rate and the ultrastructural damage to chloroplasts (Dekov and Velichkov, 1992). These results agreed with those obtained by Premachandra et. al. (1993) who concluded that higher levels of potassium fertilizer application may be beneficial for maize plants to tolerate water stress conditions.

With respect to T.W.C.310 maize plants, mean square data showed that potassium fertilizer levels and forms had significant effects on N.A.R. in both second and third growth stages. Interactions between soil water stress and potassium fertilizer levels had significant effects on that trait in the second and third growth stages.

As for soil water stress, means of N.A.R. of T.W.C. 310 corn plants in the second and third growth stages (Table 5) showed that increasing moisture stress decreased N.A.R. values from 33.83 and 31.53 gm/ m2/week at 100% of field capacity to 26.10 and 30.68 gm/ m2/week at 50% of field capacity in the two successive growth stages, however these reductions did not reach the significance level. Nir and Poljakoff Mayber (1967) concluded that loss of water from leaves resulted in a considerable reduction in photophosphorylation and photo-reductive activity of chloroplast and severe dehydration stopped these activities almost completely. On the other hand, potassium fertilizer application by any of the studied levels especially 30 and 45 kg/fed. in the two growth stages, respectively, significantly increased N.A.R. values in both growth stages. The highest N.A.R. values were 32.48 gm/ m2/week at 45 kg. K/fed in the second growth stage and 34.05 and 34.86 gm/ m2/week at 30 and 45 kg K/fed. in the third growth stage. Conversely, non-potassium application showed the lowest N.A.R. values (26.48 and 25.35 gm/ m2/week) in the second and third plant growth stages of T.W.C. 310 maize plants, respectively. Increasing N.A.R. values as a result of potassium application could be due to its effect on carbohydrate metabolism, translocation of starch, activation of various enzymes and regulation of activities of various essential elements (Ibrahim, 1982).

Table (5). Means of net assimilation rate (gm/m^2/week) of S.C.10 and T.W.C.310 maize hybrids plants in the second and third growth stages[@].

Treatments	S.C.10		T.W.C.310	
	2nd stage	3rd stage	2nd stage	3rd stage
Water stress (% of field capacity)				
100	29.63	35.33 a	33.83	31.53
75	28.88	33.15 a	27.00	30.83
50	27.23	22.20 b	26.10	30.68
L.S.D.$_{0.05}$	--	3.98	--	--
K-rates (kg/fed.)				
0	24.00 b	26.10 b	26.48 b	25.35 b
15	27.15 b	28.40 b	27.98 ab	29.78 ab
30	29.70 ab	33.40 a	28.88 ab	34.05 a
45	33.47 a	33.02 a	32.48 a	34.86 a
L.S.D.$_{0.05}$	4.80	4.73	4.05	6.75
K-Sources				
KCl	20.93 b	27.30	26.40 b	29.10 b
K_2SO_4	35.10 a	31.88	31.05 ab	30.98 ab
KNO_3	37.80 a	31.05	32.93 a	37.20 a
1:1:1	20.55 b	30.75	25.50 b	26.55 b
L.S.D.$_{0.05}$	7.13	--	5.69	6.38

@ 1st, 2nd, 3rd stages represent the first, second and third harvests on the plants aged 45, 60 and 75 days old, respectively.

As for potassium fertilizer sources effect on net assimilation ratio, potassium nitrate was significantly higher in N.A.R. values (32.93 and 37.20 gm/ m2/week) followed by potassium sulphate (31.05 and 30.98 gm/ m2/week in the second and third growth stages, respectively. However, both of potassium chloride and the mixture of the three studied forms produced the lowest N.A.R. values in the two growth stages of T.W.C310 corn plants. These might be due to the essential effects of nitrate (as a source of nitrogen) on respiration reactions, enzymes and chlorophyll structure. Also, sulphate anion is considered important component in some growth hormones as thiamin, lipoic acid and acetyl co-enzyme A. With respect to soil moisture x potassium fertilization levels interaction means, it was revealed that increasing potassium application up to 45 kg/fed at 75% of field capacity in the second growth stage or 30 and 45 kg/fed. at 75% of field capacity, in the third growth stage produced the highest N.A.R. values in

T.W.C.310 maize plants. Conversely, non-potassium application per feddan produced the lowest N.A.R. values in both growth stages. Similar results obtained by Yapa et. al. (1991) who concluded that high potassium application could overcome the deleterious effects of soil moisture stress. Premachandra et. al. (1993) also, stated that higher rates of potassium fertilization could be beneficial for corn plants to tolerate to water stress conditions.

3. Relative Growth Rate (R.G.R.):

Mean squares of the analysis of variance in showed that soil moisture stress had significant effects on relative growth rate (R.G.R.) in the second growth stage of S.C.10 maize plants. However, both potassium fertilization rate and source had significant effects on that trait in the third growth stage. On the contrary, all second and third order interactions did not reach the significance level. Means of R.G.R. values of S.C.10 plants under the three studied factors, i.e., soil moisture stress, potassium fertilization levels and forms effects in the second and third growth stages were presented in Table (6). Concerning to soil moisture stress, increasing water stress from 100 to 50% of field capacity significantly decreased R.G.R. values from 0.75 to 0.45 gm/gm/week in the second growth stage. However, these values were 0.90 and 0.60 at 100 and 50% of field capacity in the third growth stage and these reductions did not reach to the significance level in that growth stage. Because R.G.R. is a resultant of L.A.R. and N.A.R., so the effect of soil water stress on the three characters was similar.

With respect to potassium fertilization levels, the highest level (45 kg/fed.) produced the highest R.G.R. values (0.75 and 0.90 gm/gm/week) in the second and third growth stages, respectively. Conversely, the levels zero or 15 kg/fed. produced the lowest R.G. values (0.53, 0.53, 0.60 and 0.60 gm/gm/week) at zero and 15 k/fed. in the second and third growth stages. These increases in R.G.R. values did not reach to the significance level in the second growth stage. Again, potassium fertilizer levels effect on R.G.R. was similar to its effects on L.A.R. and N.A.R. traits. With regard to potassium fertilizer forms, potassium nitrate produced the highest R.G.R. values (0.75 and 0.90 gm/gm/week) followed by potassium sulphate (0.60 and 0.75 gm/gm/week) in the second and third growth stages, respectively. In contrast, potassium chloride and the mixture of the three potassium sources showed the lowest R.G.R. values in both growth stages, however, the differences between potassium sources were insignificant in the second growth stage. These might be due the effect of nitrogen nitrate on chlorophyll, enzymes structure and respiration reactions and the importance of sulphate anion in some growth hormones as thiamin and acetyl co-enzyme A.

Statistical analysis revealed that soil moisture stress had significant effects on that trait in the second and third growth stages, however, potassium fertilization forms had significant effect, only in the third growth stage. On the contrary, potassium fertilization levels and the two and three factor interactions had insignificant effects on that trait in both growth stages. Relative growth rate mean values as affected by soil moisture stress, potassium fertilization levels and forms in the second and third growth stages were presented in (Table 6). Data in that table showed that increasing water stress from 100 and 75% up to 50% of field capacity significantly decreased R.G.R. values from 0.48 and 0.98 to 0.32 and 0.52 gm/gm/week in the second and third growth stages, respectively. These results showed the important role of water availability on R.G.R. and its components, i.e., L.A.R. and N.A.R. However, potassium fertilization rates effect on R.G.R. did not reach the significance level in both second and third growth stages, but data showed that increasing potassium levels from zero to 45 kg K/fed. increased R.G.R. values from 0.34 to 0.42 gm/gm/week and from 0.70 to 0.88 gm/gm/week in the second and third growth stages, respectively.

Table (6). Means of relative growth rate (gm/gm/week) of S.C.10 and T.W.C.310 maize hybrids plants in the second and third growth stages[@].

Treatments	XVII. S.C.10		T.W.C.310	
	2nd stage	3rd stage	2nd stage	3rd stage
Water stress (% of field capacity)				
100	29.63	35.33 a	33.83	31.53
75	28.88	33.15 a	27.00	30.83
50	27.23	22.20 b	26.10	30.68
L.S.D.$_{0.05}$	--	3.98	--	--
K-rates (kg/fed.)				
0	24.00 b	26.10 b	26.48 b	25.35 b
15	27.15 b	28.40 b	27.98 ab	29.78 ab
30	29.70 ab	33.40 a	28.88 ab	34.05 a
45	33.47 a	33.02 a	32.48 a	34.86 a
L.S.D.$_{0.05}$	4.80	4.73	4.05	6.75
XVIII. K-Sources				
XIX. KCl	20.93 b	27.30	26.40 b	29.10 b
K_2SO_4	35.10 a	31.88	31.05 ab	30.98 ab
KNO_3	37.80 a	31.05	32.93 a	37.20 a
1:1:1	20.55 b	30.75	25.50 b	26.55 b
L.S.D.$_{0.05}$	7.13	--	5.69	6.38

@ 1st, 2nd, 3rd stages represent the first, second and third harvests on the plants aged 45, 60 and 75 days old, respectively.

As for potassium fertilizer forms, nitrate anion produced the highest R.G.R. (0.38 and 0.71 gm/gm/week) in the second and third growth stagers, respectively, however, the differences between the studied potassium sources were insignificant in the second growth stage. These results pointed out the importance of nitrate anion as a source of nitrogen which effects on chlorophyll structure, L.A.R. and N.A.R. Supplies of potassium nutrition may increase plant production during periods of water stress. These results are in agreement with the findings of Yapa et. al. (1991), Dekov and Velichkov (1992), Li et. al. (1996) and Bordoli and Mallarino (1998).

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