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Research Article

THE EFFECTS OF POTASSIUM APPLICATIONS ON DROUGHT STRESS IN SUGAR BEET: PART I. SUGAR BEET QUALITY COMPONENTS

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ABSTRACT

This is the first in a series of papers describing the effects of potassium applications on drought stress in sugar beet. Drought stress is the stress to which there is the most exposure in agricultural areas. In this research, the effect of potassium applications under drought stress on some quality parameters of sugar beet, which is a strategic plant, was investigated. In the experiment, irrigation levels were kept at 33%, 66% and 100% of field capacity. Different doses (10-20-40-80 mg kg-1) of potassium were applied to the plants. The plants were grown in the growth chamber under controlled conditions (day/night 16/8 hours, 25/15 0C, 60-70% humidity). A comparison of the plants irrigated at the level of 100% of the field capacity and stressed plants showed that the root sugar content decreased by 53.18% and 65.1%, and shoot sugar content by 20.8% and 17.8% respectively at 66% and 33% irrigation levels. Root white sugar content (58.61 mg g-1) was obtained at the dose of 10 mg kg-1 potassium level, while the lowest (32.61 mg g-1) was obtained at the dose of 80 mg kg-1 potassium level. Shoot protein content has increased significantly with an increasing level of potassium under drought (33% and 66%) condition. The root α-amino nitrogen content decreased under drought stress with increasing potassium concentrations while it increased in non-stressed plants. According to the results obtained from the experiment, the potassium applied to the plants under drought stress led to the increase of the root sugar, root white sugar content and shoot protein content the reduction of root α-amino nitrogen content. Therefore, it can be said that potassium may play a critical role in reducing the negative effect of drought stress in sugar beet.

Key Words: *Drought, Irrigation, Potassium, Sugar Beet.*

1. INTRODUCTION

Stress is defined as factors that preventing plant growth. According to Levitt, stress factors are divided into biotic and abiotic (Levitt, 1980). In the world, only 10% of the areas available for agriculture are not faced with any environmental stress factors (Dudal 1976). The remaining 90% of the area is under the influence of 26% drought stress, 20% salt stress, 15% cold and frost stress and 29% other stresses (Blum 1986; Ashraf 1994). Global warming is caused by climate changes that may increase drought stress. Drought is one of the main abiotic factors that limit plant growth and crop productivity (Farooq et al., 2009). Approximately 45% of the world's agricultural land is constantly exposed to drought stress (Asraf and Foolad 2007). Drought stress negatively affects of plant metabolism and plant undergoes significant changes under drought stress. These can result in plants being smaller than the normal size, early maturation, a decrease or increase in root length, an increase in root-shoot ratio, a decrease in the leaf area and weight and leaf curl (Karamanos and Papatheohari 1999; Terzi and Kadıoğlu 2006; Cattivelli et al. 2008, Jaleel et al. 2009). It has also been determined that drought stress leads to a decrease in the amount of photosynthetic pigment in plant leaves (Richardson et al. 2004). Plants increased synthesis of osmoprotectants to cope with drought stress (Fayez and Bazaid 2014). When plants are exposed to stress, they take various ions from the soil solution or synthesize some organic compounds, thereby reducing their osmotic potential (Ashraf 1994; Yordanov et al. 2003). Considering the basic function of potassium, which provides water balance, fertilizers with sufficient amount of potassium can give high yield in stress conditions (Kemmler and Krauss 1989). Plant needs higher amounts potassium for photosynthesis and assimilates transport (Wang et al. 2015). Sufficient levels of potassium increase drought resistance of plant (Eakes et al. 1991). The aim of this research is to determine the effect of potassium applications on some quality components of sugar beet, which is a strategic plant, under drought stress and to try to clarify the relationship between drought stress and potassium.

2. MATERIAL METHOD

2.1 Plant Growth

In this study, washed sand, with a pH of 8.2 and electrical conductivity of 75 μM cm^{-1}, was used. The sand was filled into 25X50 cm plastic sapling production bags. Resistive soil moisture sensors were put inside the sand to control the moisture level. Moisture sensors were calibrated with a device designed using an Arduino developer card, and irrigation was carried out according to the data received from that device (Kızıl et al. 2018). Irrigation levels were kept at 33%, 66% and 100% of field capacity. Serenad varieties of sugar beet (*Beta vulgaris* L.) plants were grown in the climate room under controlled conditions (day/night 16/8 hours, 25/15 ^{0}C, 60-70% humidity). Different doses (10-20-40-80 mg kg^{-1}) of potassium were applied to the plants with a potassium phosphate source. Plants were grown considering the 1: 0.8: 1.2, N: P: K ratio (Adiloglu and Guler 2002), with 3 replicates for 4 months. Plants were harvested after sampling the leaves for relative water content and membrane damage.

2.2 Protein content (µg g^{-1})

Samples of 500 mg were taken from plant leaves and ground in liquid nitrogen and added 1.5 ml of phosphorus buffer (pH 7). The samples were centrifuged at 4°C for 20 minutes at 14000 rpm. A sample of 5 μl, 450 μl distilled water and 5 ml Bradford reagent were added to the tubes and incubated for 15 minutes at room temperature. The samples were read in a spectrophotometer (UV/Vis) at 595 nm wavelength. Protein standards were prepared with bovine serum albumin between 0-100 μg ml^{-1} (Bradford, 1976).

2.3 Sugar content (mg g^{-1})

The shoot and root samples were dried in an oven for 48 hours at 65 °C and ground. Samples of 50 mg were taken and 2 ml of 70% ethyl alcohol was added. The mixture was incubated in a hot water bath at 80^0C for 60 minutes. The samples were centrifuged for 20 minutes at 3500 rpm. Supernatant of 1000 µl, 300 µL 5% phenol and 2000 µl concentrated sulfuric acid were put into the tubes and the reaction mixture was vortexed. The samples were read in a spectrophotometer (UV/Vis) at 488 nm wavelength. Sugar content was calculated with standard graphic prepared with sucrose (Dubois, 1956).

2.4 α-amino nitrogen content (mg kg^{-1})

Amino-nitrogen content was determined with a spectrophotometer (UV/Vis) at 623 nm wavelength using the copper method (International Commission for Uniform Methods of Sugar Analysis, 2007).

2.5 White sugar content (mg g^{-1})

White sugar content was calculated by using the data of sugar content of roots, root α-amino nitrogen content, root Na and K content by the following equation (Reinefeld et al. 1974).

White sugar content=Sugar content–(0.343(Na+K)+(0.094*α-amino nitrogen) + 0.29)

2.6 Statistical analysis

Analysis of variance (ANOVA) was performed using the general linear model (PROC GLM) procedure of R program. The variance analysis was done based on the following model:

$Yijk = \mu + Gi + Sj + (GS)ij + Mk + eijk$

Where:

Yijk: observed value

μ: grand mean

Gi: effect of irrigation i (i=1, 2, 3)

Sj: effect of potassium j (j=1, 2, 3, 4)

(GS)ij: effect of irrigation x effect of potassium

Mk: effect of replication k (k = 1, 2, 3)

eijk: random error term

Variance analysis (ANOVA) was performed by using the statistical package program using the GLM procedure. Differences between applications were determined by the Tukey multiple comparison test ($P < 0.05$).

3. RESULTS

According to the results of variance analysis, the effect of irrigation x potassium interaction shoot sugar content, root sugar content, root white sugar content was statistically significant ($P \leq 0.01$). In addition, it was determined that the effect of irrigation and potassium applications on shoot sugar content, root sugar content, root white sugar content were statistically significant (Table 1).

Table 1. Mean squares for shoot sugar content, root sugar content, root white sugar content

Source of Variation	Df	Shoot sugar content	Root sugar content	Root white sugar content
Irrigation	2	8061.41**	141.322**	8030.82**
Potassium (K)	3	1494.27**	2.551*	1486.15**
Irrigation * K	6	555.52**	18.465**	555.87**
Error	22	1.49	0.637	1.49

* , ** Indicates significant difference at $P \leq 0.05$, $P \leq 0.01$ respectively. Df: Degrees of freedom.

Shoot sugar content increased with the increase of irrigation levels to 26.34, 25.38 and 32.04 mg g^{-1} respectively. Shoot sugar content increased with potassium applications up until the 80 mg kg^{-1} potassium application (Table 2). The lowest shoot sugar content (5.29 mg g^{-1}) was obtained at the 66% irrigation level and 80 mg kg^{-1} potassium application, the highest shoot sugar content (8.94 mg g^{-1}) at the 100% irrigation level and 80 mg kg^{-1} potassium application (Table 2). When the root sugar content is considered, it is observed that root sugar content increases with increasing irrigation levels and increasing potassium applications. The lowest root sugar content (22.04 mg g^{-1}) was obtained at the 33% irrigation level and 20 mg kg^{-1} potassium application, the highest root sugar content (99.945 mg g^{-1}) at the 100% irrigation level and 80 mg kg^{-1} potassium application (Table 2).

Table 2. Mean values of shoot sugar content, root sugar content

	Irrigation (Field Capacity)				Irrigation (Field Capacity)			
K (mg kg^{-1})	**33%**	**66%**	**100%**	**Mean**	**33%**	**66%**	**100%**	**Mean**
	Shoot sugar content (mg g^{-1})				**Root sugar content (mg g^{-1})**			
10	28.43 cde	25.02fg	30.50 bc	27.98 AB	25.79 fg	23.91 gh	47.99 d	32.56 D
20	25.82 ef	29.16 cd	30.57 bc	28.51 A	22.04 h	29.28 f	57.12 c	36.15 C
40	26.23 def	24.97 f	32.84 ab	28.01 AB	33.20 e	33.31 e	94.54 b	53.68 B
80	24.90 f	22.37 g	34.25 a	27.18 B	23.36 gh	53.54 c	99.45 a	58.78 A
Mean	26.34 B	25.38 B	32.04 A		26.10 C	35.01 B	74.78 A	

†The differences between the interaction potassium and Irrigation means having different lower case letters in a column are statistically significant at 0.05 alpha level. ††The differences between the potassium means having different capital letters in a column are statistically significant at 0.05 alpha level. The differences between the irrigation means having different capital letters in a line are statistically significant at 0.05 alpha level.

White sugar content of roots is given in Table 3. White sugar content of roots increased with the increase of irrigation levels and potassium applications. The lowest root white sugar content (21.98 mg g^{-1}) was obtained at 33% irrigation level and 20 mg kg^{-1} potassium application, the highest root white sugar content (99.24 mg g^{-1}) at 100% irrigation and 80 mg kg^{-1} potassium application.

Table 3. Mean values of root white sugar content

K (mg kg^{-1})	Irrigation (Field Capacity) 33%	66%	100%	Mean
	Root white sugar content (mg g^{-1})			
10	25.73fg	23.84 gh	47.85 d	32.47 D
20	21.98 h	29.20 f	56.95 c	36.05 C
40	33.10 e	33.20 e	94.35 b	53.55 B
80	23.22gh	53.38c	99.24 a	58.61 A
Mean	26.01 C	34.90 B	74.60 A	

†The differences between the interaction potassium and Irrigation means having different lower case letters in a column are statistically significant at 0.05 alpha level. ††The differences between the potassium means having different capital letters in a column are statistically significant at 0.05 alpha level. The differences between the irrigation means having different capital letters in a line are statistically significant at 0.05 alpha level.

According to the results of variance analysis, the effect of irrigation x potassium interaction shoot protein content and root α-amino nitrogen content was statistically significant ($P \leq 0.01$). In addition, it was determined that the effect of irrigation and potassium applications on shoot protein content and root α-amino nitrogen content were statistically significant (Table 4).

Table 4. Mean squares for shoot protein content, root α-amino nitrogen content

Source of Variation	Df	Shoot protein content	Root α-amino nitrogen content
Irrigation	2	119039**	82.1126**
Potassium (K)	3	32097**	72.6078**
Irrigation * K	6	20262**	94.1099**
Error	22	95	0.0261

* , ** Indicates significant difference at $P \leq 0.05$, $P \leq 0.01$ respectively. Df: Degrees of freedom.

Shoot protein content showed an irregular change and decreased with irrigation levels to 688, 473 and 610 µg g^{-1} respectively. Protein content of shoots increased with the increase of potassium applications. The lowest shoot protein content (433 µg g^{-1}) was obtained at the 66% irrigation level and 10 mg kg^{-1} potassium application, the highest shoot protein content (900 µg g^{-1}) at the 33% irrigation level and 80 mg kg^{-1} potassium application (Table 5). Root α-amino nitrogen content increases with increasing irrigation levels to 14.11, 16.13 and 19.30 mg kg^{-1} respectively. Root α-amino nitrogen content decreased with potassium applications up until the 80 mg kg^{-1} potassium application. The lowest Root α-amino nitrogen content (11.29 mg kg^{-1}) was obtained at the 33% irrigation level and 20 mg kg^{-1} potassium application, the highest root α-amino nitrogen content (29.37 mg kg^{-1}) at the 100% irrigation level and 80 mg kg^{-1} potassium application (Table 5).

Table 5. Mean values of shoot protein content, root α-amino nitrogen content

	Irrigation (Field Capacity)				Irrigation (Field Capacity)			
K (mg kg^{-1})	**33%**	**66%**	**100%**	**Mean**	**33%**	**66%**	**100%**	**Mean**
	Shoot protein content (µg g^{-1})				**Root α-amino nitrogen content (mg kg^{-1})**			
10	552 e	433 g	588 d	524 C	17.22 d	24.51 b	14.87 e	18.86 A
20	596 d	483f	645 c	574 B	11.29 ı	14.47 ef	14.23 f	13.33 C
40	707 b	453 fg	603 d	588 B	13.69 g	12.28 h	18.71 c	14.90 B
80	900 a	525e	603 d	676 A	14.22 f	13.26 g	29.37 a	18.95 A
Mean	688 A	473C	610 B		14.11 C	16.13 B	19.30 A	

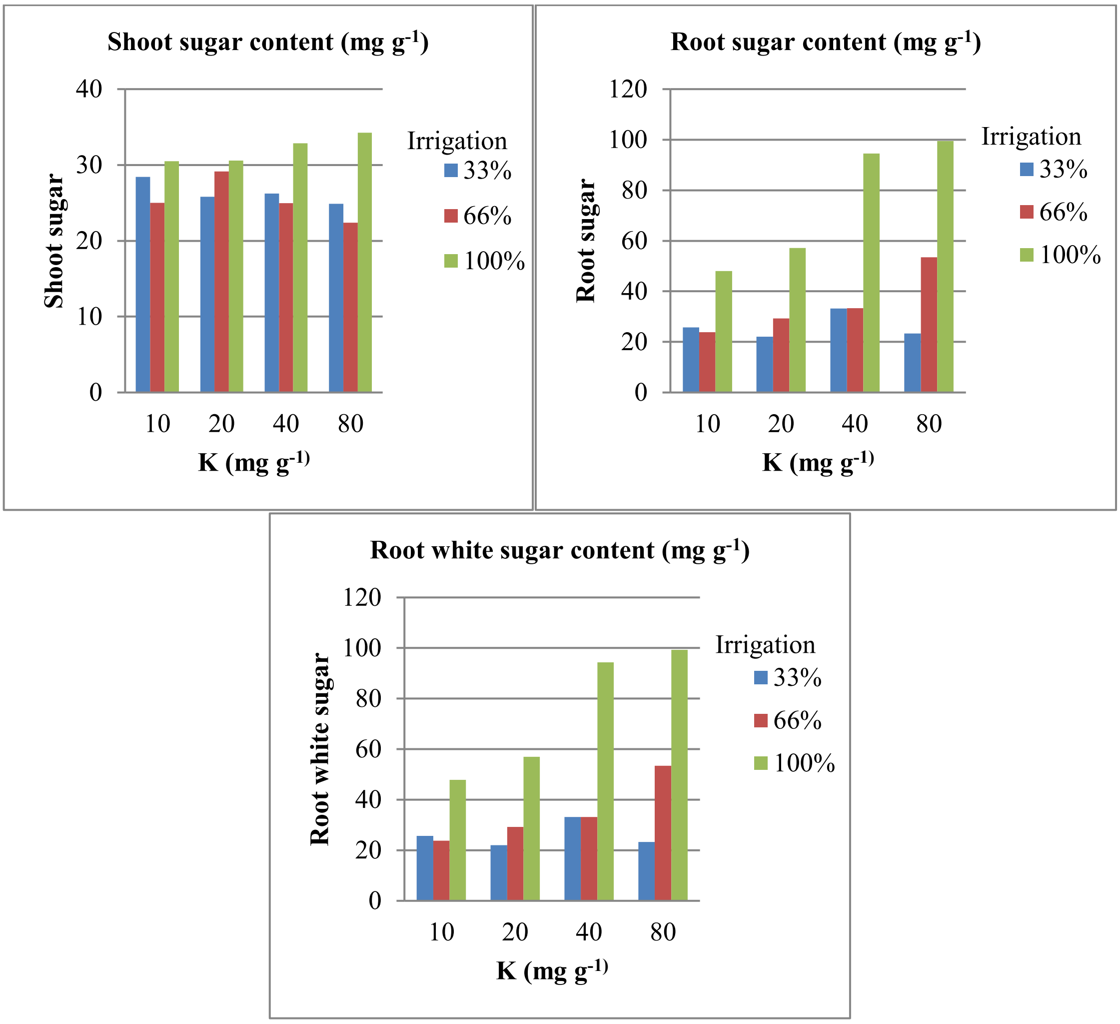
†The differences between the interaction potassium and Irrigation means having different lower case letters in a column are statistically significant at 0.05 alpha level. ††The differences between the potassium means having different capital letters in a column are statistically significant at 0.05 alpha level. The differences between the irrigation means having different capital letters in a line are statistically significant at 0.05 alpha level.

4. DISCUSSION

The accumulation of soluble sugar in plants is a response to drought stress (Zhang et al. 2009). Under drought, sugar beet sucrose storage has been found to be decreased as a result of the accumulation of ions and solutes (Hoffmann, 2010). According to the results, shoot sugar content has increased with increasing irrigation levels (Figure 1). Shoot sugar content is lower in stressed plants than plants grown under normal conditions. In the same way root sugar content increased with irrigation levels. A comparison of the plants irrigated at the level of 100% of the field capacity and stressed plants showed that the root sugar content decreased by 53.18% and 65.1%, and shoot sugar content by 20.8% and 17.8% respectively at 66% and 33% irrigation levels (Table 2). Our results are not in parallel with Shehata et al. (2000) study they found that growth and yield of sugar beet shoot were affected by drought more than the roots.

Many studies show that sugar beet reduced growth and increased sugar concentration in roots for a response to water shortage (Ucan and Gencoglan 2004, Mahmouda et al., 2018, Mansuri et al., 2018). In contrast to these studies according to our results root sugar content showed an important increment in response to the increasing levels of irrigation (Figure 1). In this study, the highest root sugar content (74.78 mg g^{-1}) was obtained at the 100% irrigation level, while the lowest (26.1 mg g^{-1}) was obtained at the 33% irrigation level. According to other researcher sugar content increased with irrigation levels (Yonts, 2011, Ghamarnia et al. 2012) and our results are in parallel with these studies.

Figure 1. Shoot sugar content, root sugar content and root white sugar content (mg g^{-1}) changes



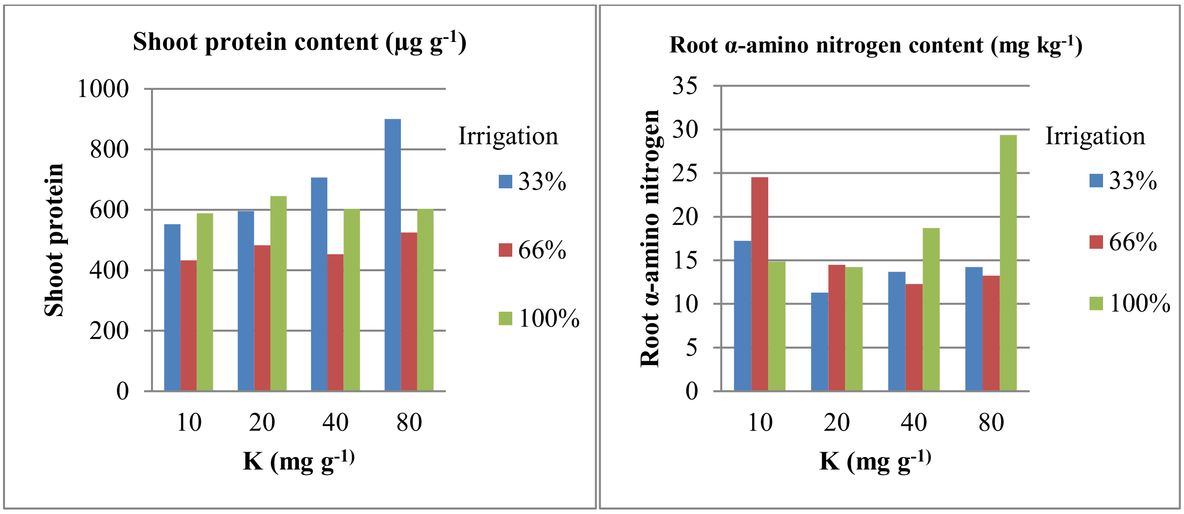
Potassium raises synthesis of carbohydrates therefore recoverable sugar content of beet was increased by increasing in potassium concentration (Milford et al 2000; Attia 2004). Potassium has important role in translocation of assimilates to sink so if sugar beet plants cannot reach sufficient potassium, translocation of photosynthates from leaves to roots reduced (Hermans et al., 2006). When Table 2 and Figure 1 are examined, it is seen that root sugar content increases with increasing potassium application which is in parallel with previous studies. According to McDonnell et al. (1966) stated that the potassium fertilizers increased root sugar content of sugar beet and on the other hand according to many researchers, the application of potassium did not affect sugar content (Bee et al., 1997; Shalaby et al., 2002 Turhan and Piskin, 2005).

When results are examined in terms of the interaction between irrigation levels and potassium, although there is a decrease with the dose of 20 mg kg^{-1} at the 33% irrigation level, root sugar content increased in parallel with the increasing potassium doses while it decreased at 80 mg kg^{-1}. The root sugar content increased parallel to the increasing potassium doses at the 66% irrigation level. According to Mubarak et al., (2016) increase in the level of potassium application at water sufficient level significantly increased plant growth, beet yield and industrial beet sugar content. The response of potassium under drought condition was also similar. Potassium could be used improve beet sugar content both under water-deficient as well as water-sufficient conditions. The most economically significant indicator in the sugar beet production is white sugar content (Dadkhah 2005). White sugar content increased in drought condition about 58.86% in compare to normal condition (Habibi, 2011).

Our results are in parallel with Masri et al., (2015) study their results showed significant increase in root yield and white sugar yield by increasing irrigation water requirement from 50% up to 75 and 100%. A comparison of the plants irrigated at the level of 100% of the field capacity and stressed plants showed that the white root sugar content decreased by 53.21% and 65.13% respectively at 66% and 33% irrigation levels (Table 3). Topak et al. (2011) reported that root and white sugar yields of sugar beet significantly decreased with drought. In contrast to this study according to our results root white sugar content showed an important increment in response to the increasing levels of irrigation (Figure 1).

Increasing the rate of potassium application resulted in significant increase white sugar yields. (Ibrahim, 2002) potassium application increment improved sugar beet quality more than its productive quality. When Table 3 and Figure 1 are examined, it is seen that root white sugar content increases with increasing potassium application which is in parallel with previous studies. In this study, the highest root white sugar content (58.61 mg g^{-1}) was obtained at the dose of 10 mg kg^{-1} potassium level, while the lowest (32.61 mg g^{-1}) was obtained at the dose of 80 mg kg^{-1} potassium level.

Figure 2. Shoot protein content (µg g^{-1}) and root α-amino nitrogen content (mg kg^{-1}) changes



When results are examined in terms of the interaction between irrigation levels and potassium, although there is a decrease with the dose of 20 mg kg^{-1} at the 33% irrigation level, root white sugar content increased in parallel with the increasing potassium doses while it decreased at 80 mg kg^{-1}.

The root white sugar content increased parallel to the increasing potassium doses at the 66% irrigation level. El-Kammah (1995) stated that the interaction between drought periods and potassium on white sugar was significant our results parallel with these studies.

According to the results, shoot protein content has decreased with increasing irrigation levels (Table 5). Shoot protein content is lower in unstressed plants than plants grown under stress conditions. In this study, the highest shoot protein content (688 µg g^{-1}) was obtained at the 33% irrigation level, while the lowest (473 µg g^{-1}) was obtained at the 66% irrigation level.

Potassium has significant effect on protein synthesis, enzyme activation, water-relation and photosynthesis in plants (Marschner 1995). Potassium keeps normal balance between carbohydrates and proteins (Moustafa and Darwish, 2001; Monreal et al., 2007). In this study, the highest shoot protein content (676 µg g^{-1}) was obtained at the dose of 80 mg kg^{-1} potassium level, while the lowest (524 µg g^{-1}) was obtained at the dose of 10 mg kg^{-1} potassium level (Figure 2).

When Table 5 is examined, it is seen that shoot protein content has increased significantly with a increasing level of potassium under dorught (33% and 66%) condition. Similar results were obtained in previous studies they have reported a positive correlation between potassium content and amino acids (Zahoor et al., 2017). According to results, potassium plays a significant role in shoot protein content under drought stress.

The root α-amino nitrogen content decreased parallel to the increasing potassium doses while it increased at 80 mg kg^{-1}. Similar to our results Ferweez and Abo El Wafa (2004) stated that root α-amino nitrogen content were increased with increasing potassium. According to many researchers, the application of potassium did not affect root α-amino nitrogen content (Bee et all., 1997; Turhan and Pişkin, 2005).

When results are examined in terms of the interaction between irrigation levels and potassium, the root α-amino nitrogen content decreased under drought stress with increasing potassium concentrations while it increased in non-stressed plants.

5. CONCLUSION

According to the results of variance analysis, the effect of irrigation x potassium interaction on the shoot sugar content, root sugar content, root white sugar content, shoot protein content and root α-amino nitrogen content was found to be statistically significant.

Root sugar content and root white sugar content increased with potassium applications under drought conditions. The root α-amino nitrogen content under drought stress decreased with increasing potassium concentrations while it increased in non-stressed plants. It is suggested that there is a great potential of potassium use in sugar beet to produce quality beet for economical industrial sugar production. The shoot protein content increased with the increase in potassium applications under drought condition. This demonstrates the role of potassium in reducing the damage of drought-dependent protein synthesis. Thus, it can be said that potassium may play a critical role in reducing the negative effects of drought stress in sugar beet. Therefore, it is thought that keeping the K nutrition at a sufficient level for the plants grown in the regions where irrigation may be a problem can be beneficial in reducing the damage of drought stress.

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