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Interactive Effects of Irrigation Intervals and Stocksorb660 Rates on Growth and Yield of Maize (*Zea mays* L.) under Conditions of Northern State, Sudan

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Abstract: A Field experiment was conducted for two seasons (2016/2017 and 2017/2018) at Dongola Research Station Farm to investigate the interactive effects of three irrigation intervals (10, 15 and 20 days) and four rates of soil conditioner known as Stocksorb660 (0, 10, 15 and 20 kg/fed) on growth and yield of maize. The experiment was carried out in split plot design, with irrigation interval comprising the main plot while the stocksorb660 rates were assigned to the sub-plot. Treatments were replicated four times. Results revealed that irrigation interval during both seasons significantly affected all measured parameters while stocksorb660 rate significantly affected cob length only during the first season. On the other hand, interaction effects were observed on grain yield. Combined analysis showed that irrespective of irrigation interval, increased rate of stocksorb660 increased the grain yield of maize. The results also showed that the combination of 15 days interval with 15 and 20 kg of stocksorb660 per feddan gave similar yields (5.0t/ha). However, irrespective of stocksorb660 rate, 10 days irrigation interval gave grain yield that ranged between 5.1 and 6.2t/ha. These results indicated that combination of 15 days interval with 15 to 20kg of stocksorb660 per feddan resulted in higher yield and saved irrigation water.

Key words: Stocksorb660, Irrigation interval, Water holding capacity, Light soil, Maize

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INTRODUCTION

Maize (*Zea mays*) is a cereal crop grown widely throughout the world in a wide range of agro-ecological environments. It is considered as the most important cereal crop in Sub-Saharan Africa (SSA) and staple food for more than 1.2 million people in SSA and Latin America. In the Sudan, maize is grown on a small scale in different locations under rainfed and irrigated sector. Water shortage and soil fertility are critical problems limiting maize production in the arid environment. The limiting water availability in the arid and semi-arid regions necessitates the use of soil conditioner for water retention and release, such as stocksorb660. Liu *et al*. (2009) reported that Super Absorbent Polymers (SAPs) can absorb more than a thousand times of their original weight in water and can retain liquids even under some pressure. Generally, SAPs enhance soils to absorb large amount of water and therefore, increase their water holding capacity and water conservation, especially if they are of light soil texture. This product creates a hydrogel when it absorbs water which is held in the polymeric network by electrostatic forces and later can be released slowly to plants when the soil is subjected to drought, which creates hydraulic gradient between in and outside areas around the root zone. Generally, the application of hydrogels is an important practice to assist plant growth by increasing soil water retention particularly in the sandy soils and its availability to plants in dry regions. The amendment with hydrogel is known to improve seed germination and seedling growth of several species. Ahmed and Verplancke (1994) reported an improvement in germination and biomass production of trifolium, lettuce and ryegrass in sand dunes with gel amendment compared to control. On the other hand, Khadem *et al*. (2010) found that super absorbent polymer has a significant impact in reducing drought stress effects and improving yield and stability in agricultural production. It was also reported that application of hydrogel decreases the irrigation requirements of several crops by improving water holding capacity, resulting in delay and onset of permanent wilting percentage under intensive evaporation (Rehman *et al*. 2011). Moreover, Yazdani *et al*. (2007) stated that under drought stress and water shortage conditions, adequate amount of super absorbent polymer (SAP) increased soybean yield and gain profit. Sayyari and Ghanbari (2012) also

concluded that application of SAP moderated the negative effect of prolonged irrigation on growth and yield of sweet pepper.
The present study focuses on evaluation of the effects of three irrigation intervals and four stocksorb660 levels on growth and yield traits of maize in the Northern State of Sudan where the soil is characterized by low water holding capacity.

MATERIALS AND METHODS

This study was conducted for two seasons (2016/2017 – 2017/2018) at Dongola research station farm (DRSF). The soil is light well drained with good physical properties (Table 1). The main objective of this research was to study the interactive effect of irrigation intervals and stocksorb660 rates on growth and yield of maize in the Northern State. The treatments consisted of three irrigation intervals and four rates of stocksorb660 as following:
Irrigation interval treatments:

Irrigation every 10 days (I_1)
Irrigation every 15 days (I_2)
Irrigation every 20 days (I_3)

Stocksorb660 rate treatments:

0 kg/fed. control (S_0)
10 kg/fed. (S_1)
15 kg/fed. (S_2)
20 kg/fed. (S_3)

Split plot design was used with four replicates. Irrigation intervals were assigned for the main plots while the stocksorb660 rates represented the sub plots, technical data of the soil conditioner are shown in Table (2). The soil conditioner was layered a few centimeters below soil surface at sowing time. Maize (Hudeiba 2) was manually planted during the first week of December for both seasons in ridges spaced 60cm apart and intra-row spacing of 25cm between holes. The sub plot size was 28m² (4.0 x 7m).

Nitrogen fertilizer in the form of urea at the rate of 40kg/fed was applied 2 weeks after sowing and then another dose (40kg/fed) of urea was applied

6 weeks after sowing. Insecticide (Profenofos+ Cypermethrin Hitcell 44% EC) was applied 4 weeks after sowing against stem borer. However, the infection of this insect was found very slight which was due to the use of seed dressing (Cruiser 350 FS Thiomethoxam) as well. The experimental plots were hand weeded twice during the growing season.

Table 1. Soil properties of the DRSF experimental site

Depth (cm)	Texture	pH	ECe	Ca CO3%	O.C%	N%	P(ppm)	ESP	Sat %
0-30	Sandy clay loam	7.6	0.4	8.0	0.16	0.047	2.0	3.0	48.1

P = Available phosphorus

Table 2. Technical data of stocksorb660

Basis	Polyacrylic acid-Potassium salt, crosslinked
Appearance	Free flowing white granules
Particle size distribution (mm)	0.8 – 2.0
Bulk density (g/l)	600 ± 60
Solubility	Insoluble in water and organical solutions; swells to a gel upon contact with aqueous fluids
pH-Value (1g/1H_2O	7.0 – 8.0
Maximum Absorption (Free swelling conditions) 1. 0.125% NPK 14-12-14 2MgO 2. Tap Water (hardness grade 4) 3. Synth, soil solution	 >80 mL/g >100 mL/g >60 mL/g
Toxicology/Ecology	Non toxic for plants, soil organism and ground water according to OECD – Test Ecology
Residual Monomers (mg/kg) Acrylic acid	<600

Source: (Evonik Nutrition & Care GmbH I STOCKOSORB660, 2020)

Plant height (cm) and cob length (cm) were measured on ten plants randomly selected in each plot at harvesting. Grain and straw yields were taken from the net area of 12 m² (2.4x5m) in each plot.

The collected data were subjected to statistical analysis using split plot analysis of variance (Mstatc). Levels of significance for 0.05, 0.01 and 0.001 probabilities for the main factors (Irrigation interval and stocksorb660 rate) and their interactions responses were calculated. Significantly different means were separated by the Duncan's Multiple Range Test (DMRT) for significance at the 0.05 level of probability.

RESULTS AND DISCUSSION

Table (3) shows the effect of stockosorb660 rates and irrigation intervals on some plant growth parameters. The cob length and plant height tended to decrease with increasing irrigation interval and stocksorb660 level during both seasons (2016/17 and 2017/18). For the cob length, no significant differences ($P<0.05$) were observed during the first season (2016/2017); however, during the second season (2017/2018), 10 day irrigation interval significantly gave taller cobs compared to the 15 and 20 day intervals. The combined analysis shows that 10 day interval significantly produced taller cobs compared to 20 day interval while no differences were observed between 10 and 15 day irrigation intervals. These results agreed with those obtained by Eltahir *et al*. (2007) who reported that well-watered plants (10 day interval) were significantly taller than those under 20 day interval. This was attributed to the fact that; well irrigated plants will have a better chance for more vigorous vegetative growth. On the other hand, cob length was significantly affected by stocksorb660 level during the first season. High level of stocksorb660 (15 and 20kg/fed.) and control treatments gave taller cob length compared to the S1 treatment (10kg/fed.). No differences were observed during the second season and combined analysis. As for plant height 10 and 15 day irrigation intervals significantly resulted in taller plants compared to 20 day irrigation interval during both seasons. However, stocksorb660 levels showed no significant differences during both seasons (Table 3). Many studies recorded that higher plant height values were obtained under SAP

amendment against the control (Abedi-Koupai and Asadkazemi, 2006; Yazdani *et al*. 2007; Fernando *et al*. 2013;). However, other studies showed contradicting results which are in line with the findings obtained in this work (Ingram and Yeager, 1987; Akhter *et al*. 2004). Their results showed no effect of soil amendment with hydrogel on emergency, early seedling growth and plant height in different plant species.

Table 3. Effect of irrigation intervals and stocksorb660 rates on cob length (cm) and plant height (cm) of maize during the (2016/17 and 2017/18) seasons

Param-eter	Cob length (cm)			Plant height (cm)		
	2016/17	2017/18	Combined	2016/17	2017/18	Combined
Irrigation interval						
I_1	16.1	14.8	15.5	185.6	193.4	189.5
I_2	15.7	14.0	14.9	182.8	184.1	183.4
I_3	15.1	13.9	14.4	175.9	172.3	176.6
SE±	0.46	0.23	0.23	2.2	2.2	1.7
L.S.	NS	*	**	*	**	**
Stocksorb660 rate						
S_0	16.1	14.5	15.3	181.3	185.4	183.4
S_1	14.7	14.0	14.4	182.2	186.5	184.4
S_2	15.8	14.4	15.1	183.2	184.2	183.8
S_3	15.9	14.1	14.9	178.8	183.7	181.3
SE±	0.36	0.35	0.26	2.7	2.78	1.9
L.S.	*	NS	NS	NS	NS	NS
CV%	8.0	8.5	8.5	5.2	5.2	5.1

L.S. = level of significance, *, ** = significant at p≤ 0.05 and 0.01 levels, respectively. NS= not significant.
I_1, I_2, and I_3 are irrigation intervals at 10, 15 and 20 days, respectively.
S_0, S_1, S_2, and S_3 are stockosorb660 rates at 0, 10, 15 and 20 kg/fed, respectively.

Table (4) shows the effect of irrigation interval and stocksorb660 rate on 100 seed weight (g) and biomass (t/ha). Results showed significant differences during the first season, where 10 and 15 day irrigation intervals significantly gave higher 100 seed weight (26.3 and 24.9g,

respectively) compared to 20 day interval (21.8g). No significant differences were observed during the second season. However, the combined analysis shows highly significant differences with 10 and 15 day intervals giving higher 100 seed weight (24.1 and 23.8g, respectively) compared to 20 day irrigation interval (21.4g). Irrespective of irrigation interval, no significant differences were observed for 100 seed weight under different stocksorb660 rates during both seasons. As for the biomass 10 day irrigation interval significantly produced higher biomass (7.4 and 9.7t/ha) compared to 20 day irrigation interval which gave 5.5 and 7.4 t/ha during the first and second seasons, respectively. No differences were observed between 10 and 15 day irrigation intervals for both seasons. Moreover, no differences were also observed for the biomass under the various stocksorb660 levels for both seasons (Table 4).

Table (5) shows the effect of irrigation interval and stockosorb660 on yield. Yield values significantly varied in response to irrigation intervals during both seasons. Results during the first season revealed that 10 day irrigation interval under various stockosorb660 rates significantly gave higher yield (6.6t/ha) compared to 20 day irrigation interval (4.7t/ha). No significant differences were observed between 10 and 15 day irrigation intervals. Interaction between the two main factors (irrigation interval and stocksorb660 rate) was statistically significant. Higher yield was obtained by the combination of 10 and 15 day irrigation intervals under different stocksorb660 levels compared to 20 day irrigation interval with zero stocksorb660 level. Generally, yield tended to increase with increasing stocksorb660 at any irrigation interval (Table 5). During the second season, yields of 10 day interval under 10 and 20 kg/fed of stocksorb660 were superior to those of 15 and 20 day irrigation intervals under 10 and 20 kg/fed of stocksorb660, respectively (Table 6). Irrespective of stocksorb660 level, 10 and 15 day irrigation intervals significantly resulted in higher yield (4.9 and 3.8t/ha, respectively) compared to 20 day irrigation interval which produced 2.9t/ha. These findings agreed with Eltahir *et al*. (2007), who reported that the well-watered plants produced significantly higher grain yield compared to the control (I_3), which is due to the fact that arid environment always requires high amounts of water to meet the crop water requirements (CWRs). Generally, irrespective of

irrigation interval, yield intended to increase with increasing stocksorb660 amount. It was reported that maize grown in soil amended with SAPs has outstepped that in the absence of SAPs (El-Rehim *et al*. 2004).

Table 4. Effect of irrigation intervals and stocksorb660 rates on 100 seed weight (g) and straw yield (t/ha) of maize during the (2016/17 and 2017/18) seasons

Param-eter	100 seed weight (g)			straw yield (t/ha)		
	2016/17	2017/18	Combined	2016/17	2017/18	Combined
Irrigation interval						
I_1	26.3	21.9	24.1	7.4	9.7	8.6
I_2	24.9	22.7	23.8	6.2	9.5	7.8
I_3	21.8	21.1	21.4	5.5	7.4	6.4
SE±	0.68	1.03	0.43	0.35	0.36	0.11
L.S.	**	NS	***	*	**	**
Stocksorb660 rate						
S_0	24.4	22.1	23.2	6.2	9.1	7.7
S_1	24.1	22.6	23.4	6.1	9.1	7.6
S_2	24.5	20.8	22.6	6.5	8.5	7.5
S_3	24.4	22.0	23.2	6.6	8.7	7.6
SE±	0.47	0.75	0.50	0.22	0.32	0.21
L.S.	NS	NS	NS	NS	NS	NS
CV%	6.7	11.8	10.6	12.1	12.3	13.8

L.S. = level of significance, *,**, *** = significant at p< 0.05, 0.01 and 0.001 levels, respectively. NS= not significant.
I_1, I_2, and I_3 are irrigation intervals at 10, 15 and 20 days, respectively.
S_0, S_1, S_2, and S_3 are stockosorb660 rates at 0, 10, 15 and 20 kg/fed, respectively

The combined analysis shows that 20 day interval without stockosorb660 and with 20 kg/fed gave the lowest yield (3.2 and 3.7t/ha, respectively) compared to 10 day irrigation interval (at any amount of stocksorb) and 15 day irrigation interval with 15 and 20 kg of stockosorb660 per feddan. On the other hand, the combined analysis (Table 7) also shows significant effect among irrigation intervals, where the 10 day interval scored higher yield (5.7 t/ha) followed by 15 day interval (4.5 t/ha) and 20 day irrigation

interval (3.8 t/ha). Interaction of irrigation interval and stocksorb660 rate was statistically significant (Table 6). The 15 day irrigation interval under 15 or 20 kg/fed of stocksorb gave 5.0 t/ha which was similar to the yield obtained under 10 day irrigation interval at any stocksorb amount which ranged between 5.1 and 6.2 t/ha.

Table 5. Effect of irrigation intervals and stocksorb660 rates on grain yield (t/ha) of maize during the (2016/17) season

Stocksorb660 rates					
2016/2017					
Irrigation interval	S_0	S_1	S_2	S_3	Mean
I_1	7.2	6.7	5.8	6.6	6.6
I_2	4.9	4.9	5.7	6.1	5.4
I_3	3.7	4.9	5.4	4.8	4.7
Mean	5.3	5.5	5.6	5.9	
	I	S	IxS		
SE±	0.36	0.198	0.47		
L.S.	*	NS	**		
CV%	12.3				

L.S. = level of significance, *,** = significant at p< 0.05, and 0.01 levels, respectively. NS= not significant.
I_1, I_2, and I_3 are irrigation intervals at 10, 15 and 20 days, respectively.
S_0, S_1, S_2, and S_3 are stockosorb660 rates at 0, 10, 15 and 20 kg/fed, respectively

Generally, yield tended to increase with increasing stocksorb660 while extending irrigation interval from 10 to 15 days (around 33% water is saved). Yield increases with increasing stockosorb may be attributed to stockosorb's application which may favor different physiological activities (photosynthesis, transpiration and intracellular Co_2). The increase in photosynthesis rate (P_N) enhances growth and drought stress, while under stomatal and non-stomatal limitations reduce P_N. Shangguan *et al.*, (1999) reported that increases SAP increased tomatoes yield. The trend in this study is in line with that obtained by Islam *et al.* (2011).

Table 6. Effect of irrigation intervals and stocksorb660 rates on grain yield (t/ha) of maize during the (2017/18) season

Stocksorb660 rates					
2016/2017					
Irrigation interval	S_0	S_1	S_2	S_3	Mean
I_1	4.5	5.6	4.3	5.1	4.9
I_2	3.6	2.8	4.4	3.9	3.8
I_3	2.7	3.2	3.1	2.6	2.9
Mean	3.6	3.9	3.9	3.9	
	I	S	IxS		
SE±	0.33	0.39	0.67		
L.S.	*	NS	NS		
CV%	35.2				

L.S. = level of significance, * = significant at p< 0.05 levels. NS= not significant.
I_1, I_2, and I_3 are irrigation intervals at 10, 15 and 20 days, respectively.
S_0, S_1, S_2, and S_3 are stockosorb660 rates at 0, 10, 15 and 20 kg/fed, respectively

Table 7. Combined effect of irrigation intervals and stocksorb660 rates on grain yield (t/ha) of maize during the (2016/17 and 2017/18) seasons

Stocksorb660 rates					
2016/2017					
Irrigation interval	S_0	S_1	S_2	S_3	Mean
I_1	5.9	6.2	5.1	5.9	5.7
I_2	4.3	3.8	5.0	5.0	4.5
I_3	3.2	4.1	4.2	3.7	3.8
Mean	4.4	4.7	4.8	4.9	
		I	S	IxS	
SE±	0.20	0.23	0.40		
L.S.	**	NS	*		
CV%	24.1				

L.S. = level of significance, *,** = significant at p< 0.05 and 0.01 levels, respectively. NS= not significant.
I_1, I_2, and I_3 are irrigation intervals at 10, 15 and 20 days, respectively.
S_0, S_1, S_2, and S_3 are stockosorb660 rates at 0, 10, 15 and 20 kg/fed, respectively

Results of moisture content at three crop stages (initial, mid-season and late-season stages) are presented in Figure (1). It was found that, moisture content was different at various crop stages. Data obtained on initial stage showed that soil moisture was similar for both depths (0-20 and 20-40cm). At the initial stage, the effect of stocksorb660 was not detected. Similarly, the 10 day irrigation interval was not affected by the amount of stocksorb660 added during the season. Overall observations showed that during mid-season and late-season stages, soil moisture tended to increase with increasing stocksorb660 amount, where the 15 day irrigation interval gave slightly higher soil moisture content compared to 20 day irrigation interval under different stocksorb660 amounts. It was also observed that during the late-season stage 15 day interval had moisture retention near to 10 day irrigation interval. These results confirmed the higher yield of maize obtained under 15 day irrigation intervals. These findings are also supported by Nangare *et al*., (2010) who reported that application of adequate amount of polymer improved water retention in soil and crop yield as well. It is worth to mention that, 10 day irrigation interval received 10 and 9 irrigations during the first and second seasons, respectively, while 15 day irrigation interval received 7 and 6 irrigations which were 30% less than 10 day irrigation interval (Table 8). In terms of water quantity, it was found that 10-day irrigation interval consumed 625 mm of water per season while 15-day irrigation interval consumed 511 mm of water per season which is equal to around 18% less amount of water used in the first season. In the second season, the amount of water in the 10-day irrigation interval was 592 mm of water per season, while that of 15-day irrigation interval was only 474 mm of water per season which is equal to 20% less amount of water used (Table 8). Moreover, soil amendment with SAPs not only helped in plant growth by increasing available water in soil but also prolonged the survival of crop under water shortage conditions (Buchholz and Graham, 1998; Hüttermann *et al*., 2009; Beniwal *et al*., 2010).

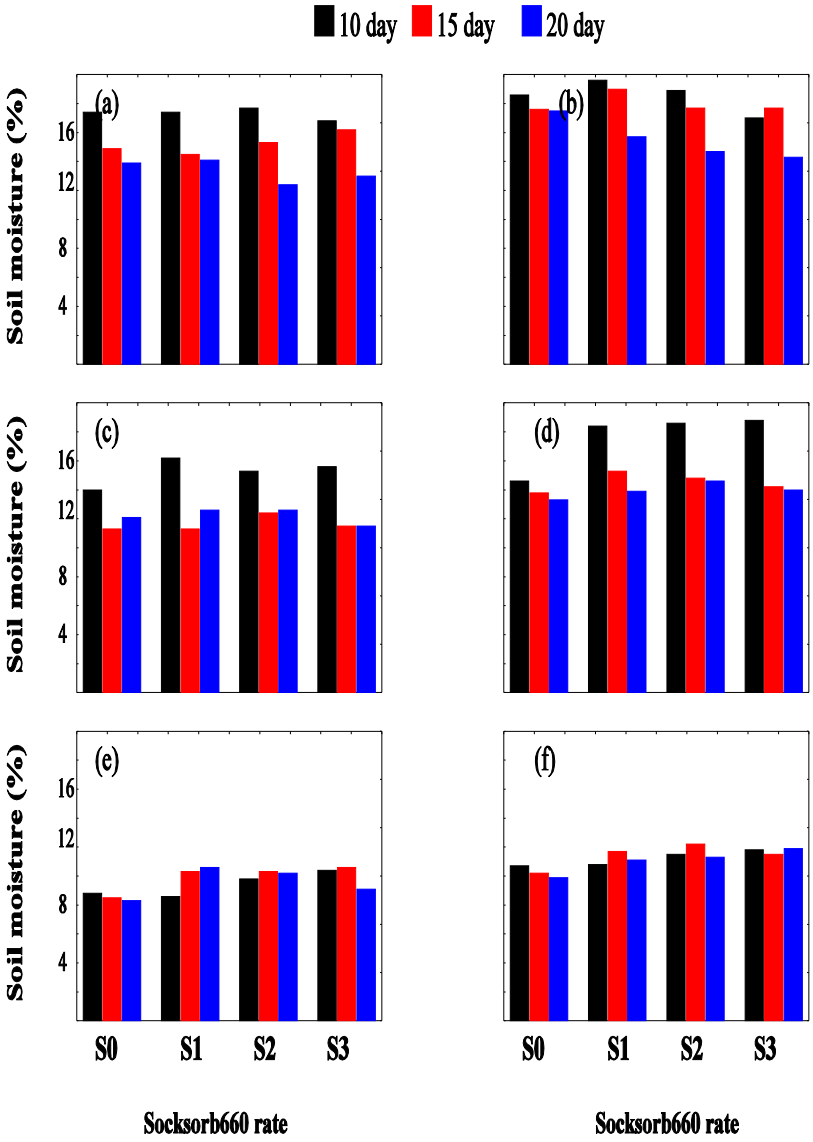

Figure (1) Soil moisture content (%) at different stages: (a) initial 0-20cm, (b) initial 20-40cm, (c) mid-season 0-20cm, (d) mid-season 20-40cm, (e) late-season 0-20cm and (f) late-season 20-40cm during season 2016/17.

Table 8. Number of irrigations and amount of applied water received during the 2016/17 and 2017/18 seasons.

Irrigation interval	No. of irrigations received during 2016/17	Applied water (mm/season) 2016/17	No. of irrigations received during 2017/18	Applied water (mm/season) 2016/17
I_1	10	625	9	592
I_2	7	511	6	474
I_3	5	444	4	416

I_1, I_2, and I_3 are irrigation intervals at 10, 15 and 20 days, respectively.

CONCLUSION

Based on the results obtained, the following points of conclusion can be drawn:

1. 10 and 15 day irrigation intervals scored higher growth and yield compared to 20 day irrigation interval.
2. Application of 15 to 20 kg/fed of stockosorb660 under 15 day irrigation interval gave similar values of yield compared to 10 day irrigation interval.
3. Using 15 day interval with 15-20 kg/fed of stockosorb660 significantly reduced number of irrigation cycles and saved irrigation water (up to 3 irrigation cycles per season).

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الأثر التفاعلي لفترات الري ومعدل مرطب التربة (Stockosorb660) علي نمو وانتاجية الذرة الشامية تحت ظروف الولاية الشمالية، السودان

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مستخلص البحث: أجريت تجربة حقلية خلال موسمي 2016/ 17 و 2017/ 18 بمزرعة محطة بحوث دنقلا وذلك لدراسة الأثر التفاعلي لثلاث فترات من الري (10 و 15 و 20 يوم) وأربع معدلات من مرطب التربة Stockosorb660 (0 و 10 و 15 و 20 كجم|الفدان) علي نمو وانتاجية الذرة الشامية. أجريت التجربة باستخدام نظام القطع المنشقة، وضعت فترات الري في الأحواض الرئيسية بينما وضعت معدلات مرطب التربة (Stockosorb660) في الأحواض الفرعية. كررت كل المعاملات أربع مرات. أظهرت النتائج أن فترات الري أثرت بصورة معنوية علي كل الصفات المقاسة خلال الموسمين بينما أثر معدل مرطب التربة (Stockosorb660) بصورة معنوية علي طول الكوز خلال الموسم الأول فقط. في المقابل، لوحظ أثر التداخل بين فترات الري و معدل مرطب التربة في الانتاجية. لقد أوضح التحليل المشترك أنه بغض النظر عن فترات الري فان زيادة معدل مرطب التربة (Stockosorb660) يزيد من انتاجية الذرة الشامية. أوضحت النتائج كذلك أن تفاعل فترة الري 15 يوم مع معدلي 15 و 20 كجم|الفدان من مرطب التربة (Stockosorb660) أعطي انتاجية مماثلة (5 طن|الهكتار). لكن بغض النظر عن معدل مرطب التربة فان فترة الري 10 يوم أعطت انتاجية تراوحت بين 5.1 و 6.2 طن|الهكتار). هذه النتائج توضح أن تفاعل فترة الري 15 يوم مع معدل يتراوح بين 15 الي 20 كجم|الفدان من مرطب التربة (Stockosorb660) يعطي أعلي انتاجية ويوفر مياه الري.

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