*Egypt. J. Soil Sci.* **Vol. 63,** No. 1, pp: 67 - 81 (2023)

# Egyptian Journal of Soil Science

**http://ejss.journals.ekb.eg/**

## Role of compost, biochar and sugar alcohols in raising the maize tolerance to water deficit conditions

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NOW, people in Egypt are under the water poverty limit a long time ago due to climate change and the shortage of water resources. These conditions hamper agricultural development in Egypt. Thus, a practical solution must be undertaken for confronting the water scarcity that hindered agricultural development in Egypt. So, two field trials were executed to assess three water levels of full irrigation [8000 $m^3$ $ha^{-1}$ as traditional full irrigation (TFI) treatment followed in the studied area (100% of TFI), 6000 $m^3$ $ha^{-1}$ (75% of TFI) and 4000 $m^3$ $ha^{-1}$ (50 % of TFI)] as main plots. While different soil conditioners [without (control), biochar (at rate of 24 Mg $ha^{-1}$) and plant compost (at rate of 24 Mg $ha^{-1}$) in addition to both of them as combined treatment (at rate of 12 Mg $ha^{-1}$ for each conditioner),1.0 Mg ″mega gram″=$10^6$ g *i.e.*, metric ton] were evaluated as subplots. Also, the foliar application of glycerol and sorbitol (0.0 and 500 mM $L^{-1}$) represented the sub-sub plots. Maize was used as an experimental plant. Findings illustrate that treatments of 75 and 50 % of TFI led to a raise in the enzymatic antioxidants production after 60 days from sowing. While both soil conditioners (either solely or in combination) and the sugar alcohols led to a decline the values of these enzymatic antioxidants. On the contrary, at the period of 90 days from sowing (growth advanced stage), the grown plants without the studied substances (soil conditioners and sugar alcohols) cannot continue producing these enzymatic antioxidants under water deficit treatments. Also, the deficit irrigation (75 and 50 % of TFI) caused a significant decline in the performance and productivity of maize compared to traditional irrigation (100 % of TFI). For example, the highest values of fresh weight (951.64 and 965.61 g $plant^{-1}$, for 1st and 2nd seasons, respectively), leaf area (620.25 and 628.56 $cm^2$ $plant^{-1}$, for 1st and 2nd seasons, respectively) and chlorophyll content (40.55 and 41.42 SPAD for 1st and 2nd seasons, respectively) were realized under traditional irrigation (100 % of TFI) followed by those values achieved under deficit irrigation treatment (75 % of TFI), while the lowest one was recorded with 50 % of TFI treatment. Regarding the soil conditioners effect, the compost and biochar either solely or in combination improved the plant performance and productivity compared to the corresponding plants grown without soil conditioners. The highest values of growth criteria and productivity were realized with the combined treatment of compost and biochar followed by compost alone then biochar alone and lately control. Concerning sugar alcohols, the sorbitol was the superior, while the glycerol came in the second order and lately control treatment. Generally, it can be concluded that a combination of compost and biochar may hold enough amounts of irrigation water and nutrients and release them as required by the maize plant, thus enhancing plant growth performance with the limited supply of irrigation water. Also, sugar alcohols have a vital role in raising maize tolerance to water deficit conditions.

**Keywords**: Irrigation techniques, soil conditioners, glycerol, sorbitol and agricultural development.

### 1. Introduction

Frost, drought, flood, salinity... *etc* are factors resulted due to climate changes, as all of them cause to occur physiological disorders in higher plants. Drought stress in particular is one of the widespread issues in the agricultural sector in arid and semi-arid regions, where

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Received: 02/12/2022; Accepted: 27/12/2022
DOI: 10.21608/EJSS.2022.178322.1556

it is one of the factors leading to plant physiological disorders. Water security in Egypt is the biggest challenge for the government due to the suffering country from severe water scarcity, especially in recent years. Now, it is known that people in Egypt are under the water poverty limit a long time ago due to climate change and the shortage of water resources. Irrigation water deficit stress is one of the vital issues in the agricultural sector, where it is one of the factors leading to plant physiological disorders via raising the production of reactive Oxygen Species (ROS) in plants tissues. These conditions hamper agricultural development in Egypt **(Rahman 2013; Yaseen*et al.* 2020; Yassin*et al.* 2021**).

The use of water-absorbent substances *e.g.,* compost, biochar, zeolite, natural polymer ...... *etc.* to increase the soil's ability to retain irrigation water may be an effective solution to meet the water requirements of the plant **(Nadeem *et al.,* 2017; Védère *et al.* 2023).**

There are many studies indicating that compost reduces the use of irrigation water because it retains a large amount of Irrigation water for a long time, and provides the soil with a large group of bacteria that have multiple important functions for the plant. More precisely, compost provides the soil with nutrients and growth regulators as well as helps to increase soil fertility and nutrient availability **(Hussein *et al.,* 2022).** Where this role restores the vitality of the soil again **(Ding *et al.,* 2021).** Moreover, compost as an organic fertilizer has influences on improving soil physical attributes *e.g.,* porosity, bulk density, hydraulic conductivity, compression strength, water-holding capacity structure and water permeability **(Alvarenga*et al.,* 2015).**

Biochar is a carbon-rich solid produced through a pyrolysis process under a high temperature (350 to 700°C) without oxygen to decompose the biomass, which consists of straw, wood, fruit peels, grass and other agricultural residues. This process results in biochar consisting of small and lightweight fragments in addition to some organic liquids and gases (**Mosa *et al.,* 2020). Bassouny and Abbas (2019)** found that applying biochar to soil was beneficial in saving irrigation water due to its pores that make it able to retain water.

Researchers have indicated that the detrimental effects associated with environmental stress might be overcome by the exogenous application of sugar alcohols (**Kaya *et al.,* 2013; Raoufi *et al.,* 2020; AL-Taee**, ***et al.,*** **2022**). One of the protective methods to raise the plant tolerance to irrigation water deficit stress may be the utilization of sugar alcohols, which are a new gene rate ion of foliar nutrients for plants **(Ma *et al.,* 2022).** Sugar alcohols are a carbohydrate which are one of the distinctive products of the photosynthesis process. Sugar alcohols move freely in the higher plant and help to obtain abundant and strong growth and improve the growth performance of the higher plants.

Glycerol, as a sugar alcohol, is a simple triol compound, aodorless, colorless, viscous liquid that is sweet tasting and non-toxic making it an ideal “environmentally friendly” agricultural chemical **(Tisserat and Stuff, 2011).** Glycerol, also called glycerine, is generally obtained from plant and animal sources where it occurs in triglycerides, esters of glycerol with long-chain carboxylic acids **(Zhang *et al.,* 2015).** Glycerol has several potential usages in agricultural fields **(Betancourt *et al.,* 2019).**

Sorbitol, a six-carbon sugar alcohol ($C_6H_{14}O_6$), is a sugar alcohol with a sweet taste and one of the most frequently found polyols in higher plants. It is a direct product of photosynthesis in mature plant leaves in parallel with sucrose and both serve similar functions like translocation of carbon skeletons and energy between sources and sink organs **(Li *et al.* 2020).** Most sorbitol is made from potato starch, but it is also found in nature, for example in apples, pears, peaches, and prunes. It is converted to fructose by sorbitol-6-phosphate 2-dehydrogenase **(Issa *et al.,* 2020).**

*Zea mays* L as a summer crop is among the greatest essential cereal crops in Egypt **(Yaseen*et al.,* 2020)** in terms of cultivated area or nutritional value (**Elsherpiny and Helmy, 2022**), as it is the third-largest cereal crop behind wheat and rice (**Ganzour*et al.,* 2020)**. The maize plant is highly affected by the climate change, and thereby the amount of applied water irrigation is expected to raise by 10-19% in 2040 (**Ouda *et al.,* 2016**) in all Egypt governorates.

Positive reports about the influences of compost, biochar, glycerol and sorbitol as eco-friendly agrochemicals on maize plant's growth and tolerance to environmental stresses encouraged us to investigate the effects of the combinations of these substances on Zea *mays* L (one of the most crops sensitive to irrigation water deficit stress, **Zhang *et al.*, 2019**). To the best of our knowledge, this is the first investigation to evaluate the combined effects of soil addition of biochar and compost as well as exogenous application of glycerol and sorbitol on maize plants grown under irrigation water deficit situations aiming to alleviate the water deficit stress and maintain acceptable yield. Maize was used as an experimental plant, where its performance and productivity are good criteria to judge the efficacy of the studied materials under water deficit conditions.

## 2. Material and Methods

- ***Experimental location***

Two field research trials were implemented at the Tag El-Ezz Experimental Farm, Agricultural Research Station (ARS), Ministry of Agric. and soil Rec. (MASR), Egypt, (31°31' 47.64" N latitude and 30°56' 12.88" E longitude) during two successive seasons of 2021 and 2022.

The Climatic elements in the studied site according to the Meteorological Authority (means) was tabulated in **Table 1.**

**Table 1. Climatic elements in the studied site according to the Meteorological Authority (means)**

| Month | Temperature (°C) | | Pan Evapotranspiration (mm) | | Humidity (%) | |
|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 |
| May | 23.0 | 23.0 | 5.1 | 5.19 | 68.7 | 68.6 |
| June | 24.6 | 24.8 | 6.1 | 6.40 | 70.9 | 71.0 |
| July | 26.5 | 26.6 | 6.45 | 6.59 | 75.9 | 77.1 |
| Aug | 28.7 | 27.3 | 6.5 | 6.30 | 75.3 | 77.0 |
| Sept | 26.99 | 26.4 | 6.0 | 6.10 | 74.9 | 73.2 |

- ***Soil Sampling***

Table 2 shows the characteristics of the initial soil**,** where the soil sample was analyzed according to the stander methods adapted from **Sparks *et al.*, (2020) and Dane and Topp (2020).**

**Table 2. Characteristics of initial soil (taken at depth of 0-30 cm) before sowing (combined data over both seasons).**

| Characteristics | | | Values |
|---|---|---|---|
| | Particle size distribution (%) | | |
| Physical properties | C. sand | | 3.400 |
| | F. sand | | 18.15 |
| | Silt | | 30.45 |
| | Clay | | 48.00 |
| | Textural class is clay | | |
| Hydro physical properties | WHC, % | | 35.07 |
| | Saturation, % | | 70.00 |
| Chemical properties | EC $dSm^{-1}$ | | 3.370 |
| | $pH^{**}$ | | 8.100 |
| | $CaCO_3$ % | | 2.130 |
| | * EC was determined in saturated soil paste extract. | | |
| | ** Soil pH was determined in soil suspension (1: 2.5). | | |
| Fertility parameters | Organic matter, % | | 1.190 |
| | Available nutrients, $mgKg^{-1}$ | Nitrogen | 38.52 |
| | | Phosphorus | 7.940 |
| | | Potassium | 201.4 |

- *Studied substances preparation*

**<u>Compost</u>**: Plant residues (rice straw) were obtained then the composting process was implemented 6 months before the execution of this field experiment at the experimental site as adapted from **Inckel *et al.* (2005).** Table 3 illustrates the attributes of the compost studied.

**Biochar:** The preparation process of biochar was executed using plant residues i.e., rice straw +maize stover under the temperature of 400-500 °C for 30 minutes without oxygen according to **Wang and Wang (2019**).

**Sugar alcohols:** Both sorbitol and glycerol were bought from Techno green Company. Then the studied level was prepared. Both sorbitol and glycerol contain Mn (1.2 and 1.4% for both, respectively), B (2.1 and 2.15 % for both, respectively), CuO (1.4 and 1.3 % for both, respectively), Zn (1.2 and 1.4% for both, respectively), MgO (1.0 and 1.0% for both, respectively) and Na (0.8 and 0.8 for both, respectively). Also, the density for both was 1.5 g $ml^{-1}$.

**Table 3. The characteristics of the studied water absorbent substances.**

| Properties | Values |
|---|---|
| **Compost** | |
| P, mg $kg^{-1}$ | 0.72 |
| Zn, mg $kg^{-1}$ | 23.0 |
| Mn, mg $kg^{-1}$ | 25.0 |
| K, mg $kg^{-1}$ | 0.95 |
| C:N ratio | 11.5 |
| Total C, % | 18.4 |
| Total N, % | 1.60 |
| pH | 6.24 |
| EC, dS $m^{-1}$ | 3.75 |
| **Biochar** | |
| EC, dS $m^{-1}$ | 4.95 |
| pH | 8.65 |
| CEC, cmolc $kg^{-1}$ | 68.0 |

- *Maize seeds.*

Maize seeds "***Zea mays* L. Cv single Hybride 10**" were obtained from ARS

- ***Experimental design and treatments***

The current trial was implemented under a split split-plot design with three replicates (Table 4). Three water levels of full irrigation [8000 $m^3$ $ha^{-1}$ as traditional full irrigation (TFI) treatment followed in the studied area (100% of TFI), 6000 $m^3$ $ha^{-1}$ (75% of TFI) and 4000 $m^3$ $ha^{-1}$ (50 % of TFI)] represented the main plots. Irrigation water was given via flood irrigation using a pump and the amount of irrigation water was measured in the light of the discharge rate of the irrigation water from this pump **(El-Maghraby *et al.* 2011).** The number of irrigations was six. While different soil conditioners [without (control), biochar (at rate of 24 Mg $ha^{-1}$) and plant compost (at rate of 24 Mg $ha^{-1}$) in addition to both of them as combined treatment (at rate of 12 Mg $ha^{-1}$ for each conditioner)] were allocated in the sub plots. Also, the foliar application of glycerol and sorbitol as sugar alcohols (0.0 and 500 mM $L^{-1}$) were devoted in sub-sub plots.

- ***Experimental setup***

The area was 10.5 $m^2$ for each sub sub-plot. The separator was 3.0 m among the irrigation treatments. Maize seeds were sown on May 28th during both seasons. Before cultivation one month, compost and biochar were mixed with the soil surface layer (0-30 cm depth) at above-mentioned levels.

Also, all plots received calcium superphosphate (6.6%P) at rate 0.50 Mg $ha^{-1}$. Ammonium sulphate (20.6 % N) was added at rate of 0.3 Mg N $ha^{-1}$, where the used dose was divided into two equal doses; the first one was applied before life watering (the 2nd irrigation), whilst the 2nd dose was applied before the next one (the 3rd irrigation). Potassium sulphate (39.8 % K) was applied at rate of 0.12 Mg $ha^{-1}$ in one dose before sowing. The source of Irrigation was Nile River, where the irrigation treatments were applied starting after the 2nd irrigation. The exogenous application of sugar alcohols was done starting from the third irrigation and repeated three times with 15 days intervals.

**Table 4. The schematic diagram illustrating the distribution of the studied treatments as related to the layout of the trial.**

| Treatments | | | Replicates | | |
|---|---|---|---|---|---|
| 100 % of IR | Control | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| | Biochar | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| | Compost | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| | Biochar + compost | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| 75 % of IR | Control | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| | Biochar | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| | Compost | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| | Biochar + compost | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| 50 % of IR | Control | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| | Biochar | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| | Compost | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |
| | Biochar + compost | Control | R1 | R2 | R3 |
| | | Glycerol | R3 | R2 | R1 |
| | | Sorbitol | R2 | R1 | R3 |

The volume of sprayed sugar alcohols solution was 600 L $ha^{-1}$. Other traditional agricultural practices were implemented according to the MASR recommendation. On September 20th, the harvest process was done.

**- *Measurement traits***

- Plant's self-production of enzymatic antioxidants *i.e.,* superoxide dismutase **(SOD),** peroxidase enzyme **(POD)** and catalase enzyme **(CAT)** were estimated using the stander methods described by **Alici and Arabaci, (2016)** at two periods (after 60 and 90 days from sowing).

- Plant's growth parameters *i.e.,* fresh and dry weights (g plant$^{-1}$) and leaf area (cm$^2$ plant$^{-1}$) were measured at period of 60 days from sowing, where leaf area was estimated using the leaf disc method **(Watson, 1952).**

- Chlorophyll content in leaves (SPAD value, F.W) was measured using a portable chlorophyll meter (SPAD-502, Soil-Plant Analysis Development (SPAD) Section, Minolta Camera, Osaka, Japan) at period of 60 days from sowing.

- Chemical content in maize tissues (stover + leaves, D.W) *i.e.,* nitrogen (using micro-Kjeldahl apparatus), phosphorus (using spectrophotometer apparatus) and potassium (using flam photometer apparatus) were determined according to **Walinga *et al*. (2013),** where the samples of maize tissues were dried then digested with the mixture of $H_2SO_4$ and $HClO_4$ (1:1) as the stander method described by **Peterburgski (1968).**

- Yield and its components *i.e.,* No. of seeds cob$^{-1}$, weight of 1000 seeds (g), cob length (cm), No. of rows cob$^{-1}$,seed yield and biological yield (Mg ha$^{-1}$) were measured at harvest stage, while harvest index was calculated as follows;

$$\textbf{Harvest index} = \frac{\text{Economical yield (grain yield)}}{\text{Biological yield (grain + straw yields)}} \times 100$$

- Bio chemical traits *i.e.,*total carbohydrates and protein as well as oil content (%) in maize seeds at harvest stage were determined according to the stander methods described in **AOAC, (2000),** where crude protein was calculated by multiplying N% in maize seeds by 5.75.

- Soil post-harvest analyses *i.e.,* available nitrogen, phosphorus, potassium and water holding capacity of soil (WHC) were determined as formerly mentioned with the initial soil.

- ***Statistical Analyses***

Data was statistically analyzed using **CoStat version 6.303 copyright (1998-2004)** according to **Gomez and Gomez, (1984)**. Treatment means were compared by using the least significant difference (LSD) at 0.05 level of probability.

**2. Results**

**- Plant's self-production of enzymatic antioxidants**

Data of Table 5 shows the effects of compost and biochar as soil conditioners with the external application of sugar alcohols *i.e.,* glycerol and sorbitol on maize plant's self-production of enzymatic antioxidants *i.e.,* superoxide dismutase (SOD), peroxidase enzyme (POD) and catalase enzyme (CAT) at various periods from maize plant's life (60 and 90 days after sowing) during two successive seasons (2021-2022).

At the period of 60 days from sowing, the data detected those plants grown under the irrigation technique which represented the water deficit (50% of TFI) had the highest values of SOD, POD and CAT (unit mg$^{-1}$ protein$^{-1}$). The second water deficit treatment (75% of TFI) came in the second order, while the traditional irrigation treatment (100% of TFI) caused the lowest values of these antioxidants in maize tissues.

At the period of 90 days from sowing, Table 3 illustrates, contrary to the period of 60 days, that the maize plants irrigated with 50% of TFI had the minimum values of SOD, POD and CAT (unit mg$^{-1}$ protein$^{-1}$) followed by the corresponding plants irrigated with 75% of TFI, while the highest one was realized with the corresponding plants irrigated with 100% of TFI.

On the other hand, the grown maize plants under control treatment (without soil addition of the water-absorbent substances) produced SOD, POD and CAT (unit mg$^{-1}$ protein$^{-1}$) more than that grown with other soil conditioners treatments at the period of 60 days from sowing. Whilst the performance at the period of 90 days from sowing differed, where self-production from SOD, POD and CAT (unit mg$^{-1}$ protein$^{-1}$) took a reverse trend. In other words, the maize plants grown on untreated soil with both biochar and compost (control) produced SOD, POD and CAT (unit mg$^{-1}$ protein$^{-1}$) less than that grown on soil treated with soil conditioners (either solely or in combination), taking in consideration that combined treatment of compost and biochar was superior in producing these antioxidants followed by compost alone then biochar alone.

Data of the same Table show that the maize plants treated with sugar alcohols produced SOD, POD and CAT (unit $mg^{-1}$ $protein^{-1}$) at the period of 60 days from sowing less than the grown maize plants without exogenous application of both sorbitol and glycerol. While at the period of 90 days from sowing, the highest values of SOD, POD and CAT (unit $mg^{-1}$ $protein^{-1}$) were recorded with the maize plants sprayed with sorbitol followed by glycerol and lately control treatment (without sugar alcohols). The same trend was found for both studied seasons.

**Table 5. Effect of compost, biochar and sugar alcohols on plant's self-production of enzymatic antioxidants at various periods from maize plant's life (60 and 90 days after sowing) during two successive seasons (2021-2022).**

| Treatments | Enzymatic antioxidants at 60 days | | | | Enzymatic antioxidants at 70 days | | | | Enzymatic antioxidants at 90 days | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Superoxide dismutase (SOD) | | Peroxidase Enzyme (POD) | | Catalase enzyme (CAT) | | Superoxide dismutase (SOD) | | Peroxidase Enzyme (POD) | | Catalase enzyme (CAT) | |
| | (unit $mg^{-1}$ $protein^{-1}$) | | | | | | | | | | | |
| | 1st season | 2nd season | 1st season | 2nd season | 1st season | 2nd season | 1st season | 2nd season | 1st season | 2nd season | 1st season | 2nd season |
| **Irrigation techniques** | | | | | | | | | | | | |
| **$I_1$** | 71.03c | 71.56c | 182.48c | 184.10c | 68.43c | 69.22c | 74.13a | 75.03a | 221.09a | 223.96a | 76.82a | 78.09a |
| **$I_2$** | 73.36b | 74.25b | 193.16b | 195.56b | 72.83b | 73.78b | 71.37b | 72.43b | 208.08b | 211.31b | 72.55b | 73.65b |
| **$I_3$** | 82.98a | 83.95a | 247.97a | 250.83a | 87.68a | 88.71a | 63.04c | 64.13c | 159.42c | 162.21c | 60.21c | 61.23c |
| **LSD at 5%** | **0.15** | **0.18** | **0.48** | **1.98** | **0.03** | **0.13** | **0.08** | **0.13** | **1.07** | **0.20** | **0.15** | **0.04** |
| **Soil conditioners** | | | | | | | | | | | | |
| **$S_1$** | 79.63a | 80.30a | 228.77a | 230.69a | 82.64a | 83.59a | 65.84d | 66.92d | 176.98d | 179.89d | 64.33d | 65.39d |
| **$S_2$** | 75.77b | 76.69b | 208.18b | 210.87b | 76.44b | 77.43b | 69.50c | 70.41c | 196.26c | 198.85c | 69.80c | 70.93c |
| **$S_3$** | 74.46c | 75.37c | 200.72c | 203.21c | 74.11c | 74.99c | 70.73b | 71.70b | 202.64b | 205.67b | 71.69b | 72.76b |
| **$S_4$** | 73.31d | 73.97d | 193.81d | 195.88d | 72.06d | 72.94d | 71.98a | 73.09a | 208.91a | 212.23a | 73.63a | 74.88a |
| **LSD at 5%** | **0.12** | **0.08** | **0.37** | **0.87** | **0.11** | **0.09** | **0.10** | **0.14** | **0.86** | **0.28** | **0.09** | **0.09** |
| **Sugar alcohols** | | | | | | | | | | | | |
| **$F_1$** | 76.24a | 77.03a | 210.53a | 212.75a | 77.08a | 78.04a | 69.10c | 70.07c | 193.77c | 196.57c | 69.17c | 70.28c |
| **$F_2$** | 75.78b | 76.60b | 207.69b | 210.19b | 76.32b | 77.32b | 69.53b | 70.54b | 196.10b | 199.13b | 69.86b | 71.01b |
| **$F_3$** | 75.36c | 76.12c | 205.39c | 207.55c | 75.53c | 76.36c | 69.91a | 70.98a | 198.71a | 201.78a | 70.55a | 71.67a |
| **LSD at 5%** | **0.16** | **0.17** | **0.40** | **1.32** | **0.1** | **0.18** | **0.15** | **0.17** | **1.28** | **0.43** | **0.15** | **0.14** |
| **Interactions** | | | | | | | | | | | | |
| **I X S x F** | **LSD at 5%** | | | | | | | | | | | |
| | **0.56** | **0.57** | **1.38** | **4.55** | **0.59** | **0.64** | **0.53** | **0.58** | **4.34** | **1.50** | **0.52** | **0.53** |

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

**$I_1$:** 100% of TFI; **$I_2$:** 75% of TFI; **$I_3$:** 50% of TFI; **$S_1$:** without soil conditioner (control); **$S_2$:** biochar alone; **$S_3$:** compost alone; **$S_4$:** biochar + compost; **$F_1$**: without sugar alcohols (control); **$F_2$**: glycerol and **$F_3$:** Sorbitol.

**- Growth criteria and chemical constituents at period of 60 days from sowing**

Data of Table 4 illustrates the individual and interaction effects of the studied treatments on the plant's growth criteria *i.e.*, fresh and dry weights (g $plant^{-1}$) and leaf area ($cm^2$ $plant^{-1}$), leaves chlorophyll pigment (SPAD) and chemical constituents in maize tissues *i.e.*, N,P and K(%) at period of 60 days from sowing during two successive seasons of 2021 and 2022.

Findings show that deficit irrigation (75 and 50 % of TFI) caused a significant decline in the performance growth of maize compared to traditional irrigation (100 % of TFI). In other words, the highest values of growth criteria and tissues chemical constituents *e.g.*, fresh weight (951.64 and 965.61 g $plant^{-1}$, for 1st and 2nd seasons, respectively), leaf area (620.25 and 628.56 $cm^2$ $plant^{-1}$, for 1st and 2nd seasons, respectively) and chlorophyll content (40.55 and 41.42 SPAD for 1st and 2nd seasons, respectively) were realized under traditional irrigation (100 % of TFI) followed by those values achieved under deficit irrigation treatment (75 % of TFI), while the lowest one were recorded with deficit irrigation treatment (50 % of TFI).

Regarding soil conditioners effect, the compost and biochar either solely or in combination significantly improved the plant performance at the period of 60 days from sowing expressed in fresh and dry weights (g plant$^{-1}$), leaf area (cm$^2$ plant$^{-1}$), leaves chlorophyll pigment (SPAD) and chemical constituents in maize tissues *i.e.,* N, P and K(%) compared to the corresponding plants grown without soil conditioners. The highest values of all aforementioned growth criteria and tissue chemical content were realized with the combined treatment of compost and biochar followed by compost alone then biochar alone and lately control treatment (without soil conditioner).

**Table 6. Effect of compost, biochar and sugar alcohols on plant's growth criteria, chlorophyll pigment and chemical constituents in maize tissues at period of 60 days from sowing during two successive seasons (2021-2022).**

| Treatments | Growth criteria | | | | | | Chlorophyll pigment, SPAD | | Chemical constituents | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fresh weight, g plant$^{-1}$ | | Dry weight, g plant$^{-1}$ | | Leaf area, cm$^2$ plant$^{-1}$ | | | | N,% | | P,% | | K,% | |
| | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd | 1st | 2nd |
| **Irrigation techniques** | | | | | | | | | | | | | | |
| $I_1$ | 951.64a | 965.61a | 329.92a | 334.72a | 620.25a | 628.56a | 40.55a | 41.42a | 3.31a | 3.38a | 0.375a | 0.382a | 3.12a | 3.15a |
| $I_2$ | 892.78b | 903.64b | 305.81b | 310.50b | 594.86b | 604.19b | 38.64b | 39.50b | 2.99b | 3.05b | 0.344b | 0.351b | 2.85b | 2.91b |
| $I_3$ | 741.56c | 752.83c | 249.92c | 253.72c | 528.53c | 536.67c | 33.06c | 33.77c | 2.47c | 2.53c | 0.285c | 0.290c | 2.39c | 2.44c |
| **LSD at 5%** | **9.80** | **0.56** | **2.61** | **1.48** | **1.45** | **1.02** | **0.16** | **0.09** | **0.01** | **0.01** | **0.002** | **0.002** | **0.06** | **0.02** |
| **Soil conditioners** | | | | | | | | | | | | | | |
| $S_1$ | 795.15d | 803.81d | 268.59d | 272.41d | 550.22d | 558.30d | 35.08d | 35.86d | 2.65d | 2.71d | 0.303d | 0.309d | 2.54d | 2.59d |
| $S_2$ | 858.85c | 871.59c | 294.37c | 299.11c | 580.22c | 589.04c | 37.13c | 38.00c | 2.91c | 2.98c | 0.333c | 0.341c | 2.79c | 2.82c |
| $S_3$ | 884.33b | 897.85b | 304.44b | 308.78b | 591.81b | 600.22b | 38.24b | 39.00b | 3.00b | 3.07b | 0.345b | 0.351b | 2.85b | 2.91b |
| $S_4$ | 909.63a | 922.85a | 313.44a | 318.30a | 602.59a | 611.67a | 39.22a | 40.05a | 3.12a | 3.19a | 0.357a | 0.363a | 2.96a | 3.02a |
| **LSD at 5%** | **7.60** | **1.89** | **1.93** | **1.71** | **2.88** | **1.29** | **0.17** | **0.04** | **0.02** | **0.02** | **0.001** | **0.001** | **0.04** | **0.02** |
| **Sugar alcohols** | | | | | | | | | | | | | | |
| $F_1$ | 855.00b | 865.14c | 291.89c | 296.17c | 577.36c | 585.89c | 37.10c | 37.92c | 2.89c | 2.95c | 0.331c | 0.337c | 2.74b | 2.79c |
| $F_2$ | 861.25b | 874.08b | 295.17b | 299.53b | 581.19b | 589.86b | 37.45b | 38.24b | 2.92b | 2.99b | 0.334b | 0.341b | 2.81a | 2.85b |
| $F_3$ | 869.72a | 882.86a | 298.58a | 303.25a | 585.08a | 593.67a | 37.71a | 38.53a | 2.96a | 3.02a | 0.339a | 0.346a | 2.82a | 2.87a |
| **LSD at 5%** | **6.50** | **1.85** | **1.53** | **1.88** | **2.23** | **1.19** | **0.15** | **0.08** | **0.02** | **0.02** | **0.002** | **0.002** | **0.04** | **0.02** |
| **Interactions** | | | | | | | | | | | | | | |
| **I X S x F** | **LSD at 5%** | | | | | | | | | | | | | |
| | **22.54** | **6.43** | **5.27** | **6.52** | **7.73** | **4.11** | **0.54** | **0.29** | **0.06** | **0.07** | **0.008** | **0.008** | **0.13** | **0.06** |

Means within a row followed by a different letter (s) are statistically different at a 0.05% level.

**$I_1$:** 100% of TFI; **$I_2$:** 75% of TFI; **$I_3$:** 50% of TFI; **$S_1$:** without soil conditioner (control); **$S_2$:** biochar alone; **$S_3$:** compost alone; **$S_4$:** biochar + compost; **$F_1$**: without sugar alcohols (control); **$F_2$**: glycerol and **$F_3$:** Sorbitol.

Concerning sugar alcohols, the exogenous application of sorbitol was the superior treatment, while the glycerol came in the second order and lately control treatment (without sugar alcohols).

Also, it can be noticed that the combined treatment of both biochar and compost (at a rate of 12 Mg ha$^{-1}$ for each conditioner) + foliar application of sorbitol under traditional irrigation technique (100 % of TFI) was the superior treatment for obtaining the best growth performance. Taking into consideration that the addition of both biochar and compost (either solely or in combination), before sowing with deficit irrigation treatment (75 % of TFI) recorded better results of growth performance and chemical content in maize tissues at the period of 60 days from sowing compared to non-addition of soil conditioners under traditional irrigation technique (100 % of TFI).The same trend was achieved for both seasons.

**- Yield and its components at harvest stage.**

Tables 5 and 6 point out the individual and interaction effects of compost, biochar and sugar alcohols on maize yield and its components *i.e.*, No. of seeds $cob^{-1}$, weight of 1000 seeds (g), cob length (cm), No. of rows $cob^{-1}$,seed yield and biological yield (Mg $ha^{-1}$) as well as some grain biochemical traits *i.e.*, total carbohydrates, protein and oil content (%) at harvest stage during the two successive seasons of 2021 and 2022.

It is clear that all aforementioned traits were significantly affected due to the studied irrigation techniques, where the values significantly decreased as irrigation requirements were reduced. In other words, the highest values of the aforementioned traits were recorded under traditional irrigation (100 % of TFI) followed by those values achieved under deficit irrigation treatment (75 % of TFI), while the lowest ones were recorded with deficit irrigation treatment (50 % of TFI).

Regarding soil addition of biochar and compost treatments, the data of the same Tables illustrate pronouncedly differences between both additional soil conditioners. The combined treatment of compost and biochar came in the first order for obtaining the highest values of all aforementioned traits followed by compost alone then biochar alone, while the control treatment (without soil conditioner) came in the last order. Regarding sugar alcohols, the foliar application of sorbitol came in the first order for obtaining the highest values of all aforementioned traits, while the glycerol came in the second order and lately control treatment (without sugar alcohols).

Also, it can be noticed that the combined treatment of both biochar and compost (at a rate of 12 Mg $ha^{-1}$ for each conditioner) + foliar application of sorbitol under traditional irrigation technique (100 % of TFI) was the superior treatment for obtaining the highest values of No. of seeds $cob^{-1}$, weight of 1000 seeds (g), cob length (cm), No. of rows $cob^{-1}$,seed yield and biological yield (Mg $ha^{-1}$) as well as some grain bio chemical traits *i.e.*, total carbohydrates, protein and oil content (%). Taking into consideration that the addition of both biochar and compost (either solely or in combination), before sowing with deficit irrigation treatment (75 % of TFI) recorded better results of all aforementioned trats compared to non-addition of soil conditioners under traditional irrigation technique (100 % of TFI).

**Table 7. Effect of compost, biochar and sugar alcohols on maize yield and its components at harvest stage during two successive seasons (2021-2022).**

| Treatments | Physical traits | | | | | | | | Yield | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. seeds $cob^{-1}$ | | Weight of 1000 seed, g | | Cob length, cm | | No. of rows $cob^{-1}$ | | Grain yield, Mg $ha^{-1}$ | | Biological yield, Mg $ha^{-1}$ | |
| | 1st season | 2nd season | 1st season | 2nd season | 1st season | 2nd season | 1st season | 2nd season | 1st season | 2nd season | 1st season | 2nd season |
| **Irrigation techniques** | | | | | | | | | | | | |
| **$I_1$** | 389.92a | 395.36a | 36.00a | 36.91a | 24.37a | 24.74a | 15.44a | 16.69a | 6.83a | 6.96a | 12.99a | 13.23a |
| **$I_2$** | 364.97b | 370.14b | 35.44b | 35.92b | 21.58b | 21.94b | 13.75b | 14.69b | 6.35b | 6.47b | 12.31b | 12.54b |
| **$I_3$** | 283.75c | 288.22c | 31.33c | 31.73c | 14.59c | 14.85c | 10.28c | 10.94c | 4.53c | 4.63c | 10.45c | 10.66c |
| **LSD at 5%** | **1.68** | **1.64** | **0.03** | **0.02** | **0.08** | **0.09** | **0.86** | **0.50** | **0.10** | **0.07** | **0.14** | **0.20** |
| **Soil conditioners** | | | | | | | | | | | | |
| **$S_1$** | 313.33d | 318.07d | 32.72d | 33.24d | 16.93d | 17.23d | 11.41d | 12.11d | 5.10d | 5.21d | 11.12d | 11.36d |
| **$S_2$** | 346.37c | 350.67c | 34.38c | 34.85c | 20.23c | 20.55c | 13.04c | 13.93c | 5.89c | 6.02c | 11.87c | 12.08c |
| **$S_3$** | 356.19b | 361.67b | 34.76b | 35.45b | 21.22b | 21.57b | 13.70b | 14.78b | 6.19b | 6.30b | 12.15b | 12.36b |
| **$S_4$** | 368.96a | 374.56a | 35.18a | 35.87a | 22.34a | 22.69a | 14.48a | 15.63a | 6.42a | 6.54a | 12.52a | 12.77a |
| **LSD at 5%** | **1.74** | **1.96** | **0.05** | **0.04** | **0.11** | **0.11** | **0.63** | **0.56** | **0.04** | **0.04** | **0.08** | **0.06** |
| **Sugar alcohols** | | | | | | | | | | | | |
| **$F_1$** | 341.14c | 346.22c | 34.08c | 34.64c | 19.79c | 20.10c | 12.89a | 13.78b | 5.79c | 5.91c | 11.82c | 12.05c |
| **$F_2$** | 346.81b | 351.86b | 34.26b | 34.85b | 20.19b | 20.52b | 13.17a | 14.14ab | 5.91b | 6.03b | 11.91b | 12.15b |
| **$F_3$** | 350.69a | 355.64a | 34.44a | 35.07a | 20.57a | 20.91a | 13.42a | 14.42a | 6.00a | 6.11a | 12.01a | 12.23a |
| **LSD at 5%** | **1.35** | **2.22** | **0.07** | **0.07** | **0.13** | **0.13** | **N.S** | **0.58** | **0.04** | **0.04** | **0.08** | **0.08** |
| **Interactions** | | | | | | | | | | | | |
| **I X S x F** | **LSD at 5%** | | | | | | | | | | | |
| | **4.66** | **7.68** | **0.26** | **0.24** | **0.45** | **0.46** | **N.S** | **N.S** | **0.14** | **0.14** | **0.28** | **0.27** |

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

**$I_1$:** 100% of TFI; **$I_2$:** 75% of TFI; **$I_3$:** 50% of TFI; **$S_1$:** without soil conditioner (control); **$S_2$:** biochar alone; **$S_3$:** compost alone; **$S_4$:** biochar + compost; **$F_1$**: without sugar alcohols (control); **$F_2$**: glycerol and **$F_3$:** Sorbitol.

**Table 8. Effect of compost, biochar and sugar alcohols on harvest index and maize grain quality traits at harvest stage during two successive seasons (2021-2022).**

| Treatments | Harvest index, % | | Maize grain quality traits | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Carbohydrates, % | | Protein, % | | Oil, % | |
| | 1st season | 2nd season | 1st season | 2nd season | 1st season | 2nd season | 1st season | 2nd season |
| **Irrigation techniques** | | | | | | | | |
| **$I_1$** | 52.47a | 52.50a | 73.03a | 74.19a | 15.65a | 15.90a | 6.24a | 6.36a |
| **$I_2$** | 51.49b | 51.55b | 71.16b | 72.20b | 14.55b | 14.77b | 5.68b | 5.80b |
| **$I_3$** | 43.19c | 43.23c | 66.17c | 67.29c | 11.22c | 11.40c | 3.60c | 3.69c |
| **LSD at 5%** | **0.28** | **0.33** | **0.16** | **0.12** | **0.03** | **0.11** | **0.07** | **0.04** |
| **Soil conditioners** | | | | | | | | |
| **$S_1$** | 45.46d | 45.45d | 67.32d | 68.43d | 12.32d | 12.52d | 4.30d | 4.40d |
| **$S_2$** | 49.14c | 49.31c | 70.16c | 71.28c | 13.78c | 13.99c | 5.18c | 5.30c |
| **$S_3$** | 50.54b | 50.64b | 71.15b | 72.17b | 14.26b | 14.47b | 5.46b | 5.57b |
| **$S_4$** | 51.06a | 50.99a | 71.85a | 73.04a | 14.87a | 15.12a | 5.75a | 5.86a |
| **LSD at 5%** | **0.30** | **0.18** | **0.17** | **0.34** | **0.03** | **0.06** | **0.04** | **0.05** |
| **Sugar alcohols** | | | | | | | | |
| **$F_1$** | 48.50b | 48.54c | 69.83c | 70.95b | 13.64c | 13.86c | 5.06c | 5.17c |
| **$F_2$** | 49.14a | 49.20b | 70.15b | 71.28a | 13.76b | 13.98b | 5.17b | 5.28b |
| **$F_3$** | 49.51a | 49.55a | 70.37a | 71.46a | 14.02a | 14.23a | 5.29a | 5.39a |
| **LSD at 5%** | **0.43** | **0.32** | **0.13** | **0.28** | **0.03** | **0.04** | **0.04** | **0.03** |
| **Interactions** | | | | | | | | |
| **I X S x F** | **LSD at 5%** | | | | | | | |
| | **1.50** | **1.12** | **0.46** | **0.97** | **0.09** | **0.15** | **0.12** | **0.10** |

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

$I_1$: 100% of TFI; $I_2$: 75% of TFI; $I_3$: 50% of TFI; $S_1$: without soil conditioner (control); $S_2$: biochar alone; $S_3$: compost alone; $S_4$: biochar + compost; $F_1$: without sugar alcohols (control); $F_2$: glycerol and $F_3$: Sorbitol.

**- Post-harvest soil properties**

Data showed in Figs 1, 2, 3 and 5 illustrate the impact of the compost, biochar and sugar alcohols on soil available nutrients *i.e.*, N, P and K (mg $kg^{-1}$) and soil water holding capacity (WHC,%) (Combined data over both seasons).

***Soil N, P and K.***

The soil under traditional irrigation technique (100% of TFI) had the lowest values of soil available N, P, K (mg $kg^{-1}$) (Fig 1, 2 and 3) as a result of improving the growth performance under this irrigation technique compared to water deficit techniques (50 and 75 % of TFI).

In other words, the maize plants irrigated according to the followed traditional method absorbed more nitrogen, phosphorus and potassium from soil, as this behavior made the residues of these nutrients in the studied soil after harvest less. Also, usage both compost and biochar conditioners clearly increased the studied nutrients compared to the corresponding soil without additional water absorbent substances. The content of these nutrients in soil treated with compost as organic fertilizer was more than that treated with biochar conditioner and this may attributed to the high content of the first water absorbent substance from nutrients and organic matter. On the hand, the highest content of these nutrients was recorded in soil treated with the combined treatment of compost and biochar.

The same Table indicates that exogenous application of both sugar alcohols led to a decline in the values of these nutrients compared to the corresponding soil containing plants grown without both sugar alcohols. This may be owing to the role of both sugar alcohols in improving maize plant status. This improvement may be as a result of raising maize plants absorption of these nutrients from soil more than untreated maize plants. Taking into consideration that plant uptake from these nutrients with sorbitol was more than glycerol, thus the values of available soil N, P and K was less with sorbitol than glycerol.

***Soi lwater holding capacity (WHC, %).***

Irrigation techniques and sugar alcohol treatments had an unclear impact on the value of soil WHC (%) of soil, while the most effective factor was compost and biochar. Hence, the presentation of the results will be confined to their influences (Fig4). WHC value of soil increased with all soil conditioners treatments at harvest stage compared to corresponding soil without any conditioner due to the ability of both studied in holding a high quantity of Irrigation water. The combined treatment of compost and biochar caused the highest value of soil WHC followed by biochar alone then compost alone.

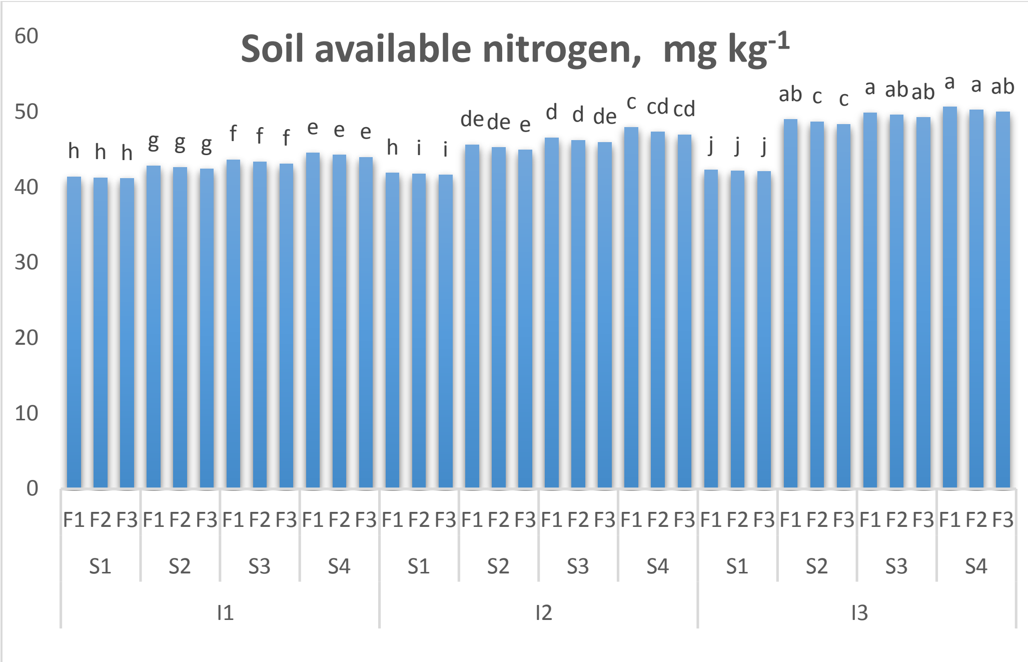


**Fig. 1. Impact of the compost, biochar and sugar alcohols on soil available nitrogen after harvest during two successive seasons (2021-2022) (combined data over both seasons).**

**$I_1$:** 100% of TFI; **$I_2$:** 75% of TFI; **$I_3$:** 50% of TFI; **$S_1$:** without soil conditioner (control); **$S_2$:** biochar alone; **$S_3$:** compost alone; **$S_4$:** biochar + compost; **$F_1$**: without sugar alcohols (control); **$F_2$**: glycerol and **$F_3$:** Sorbitol**.**

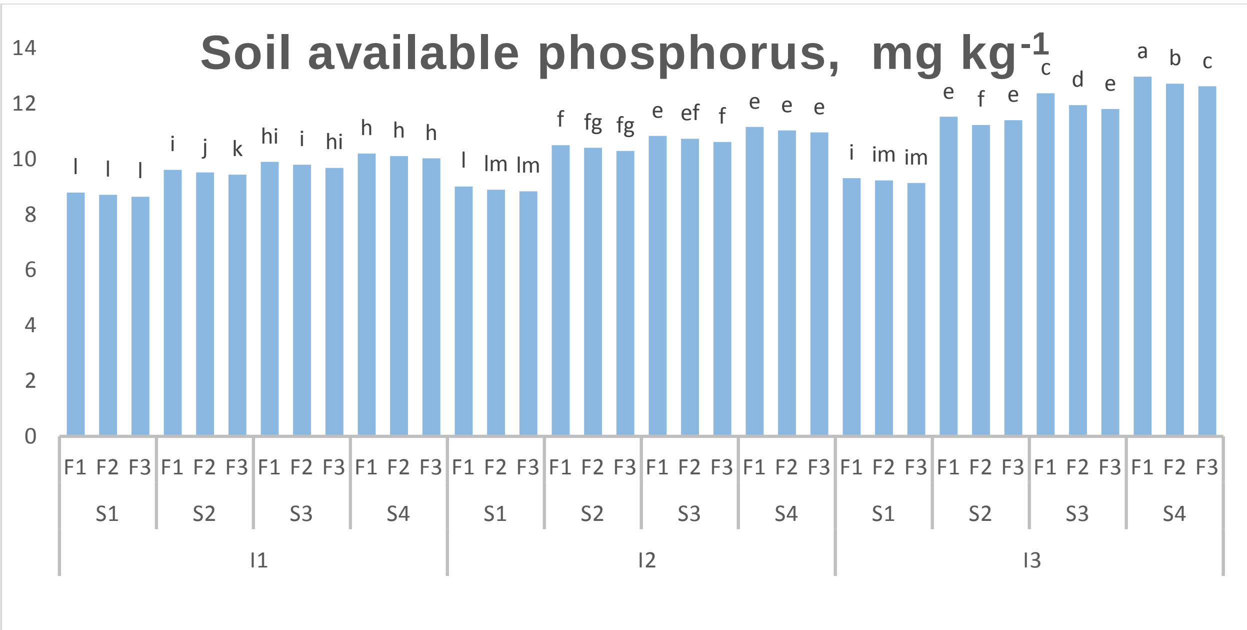


**Fig. 2. Impact of the compost, biochar and sugar alcohols on soil available phosphorus after harvest during two successive seasons (2021-2022) (combined data over both seasons).**

**$I_1$:** 100% of TFI; **$I_2$:** 75% of TFI; **$I_3$:** 50% of TFI; **$S_1$:** without soil conditioner (control); **$S_2$:** biochar alone; **$S_3$:** compost alone; **$S_4$:** biochar + compost; **$F_1$**: without sugar alcohols (control); **$F_2$**: glycerol and **$F_3$:** Sorbitol.

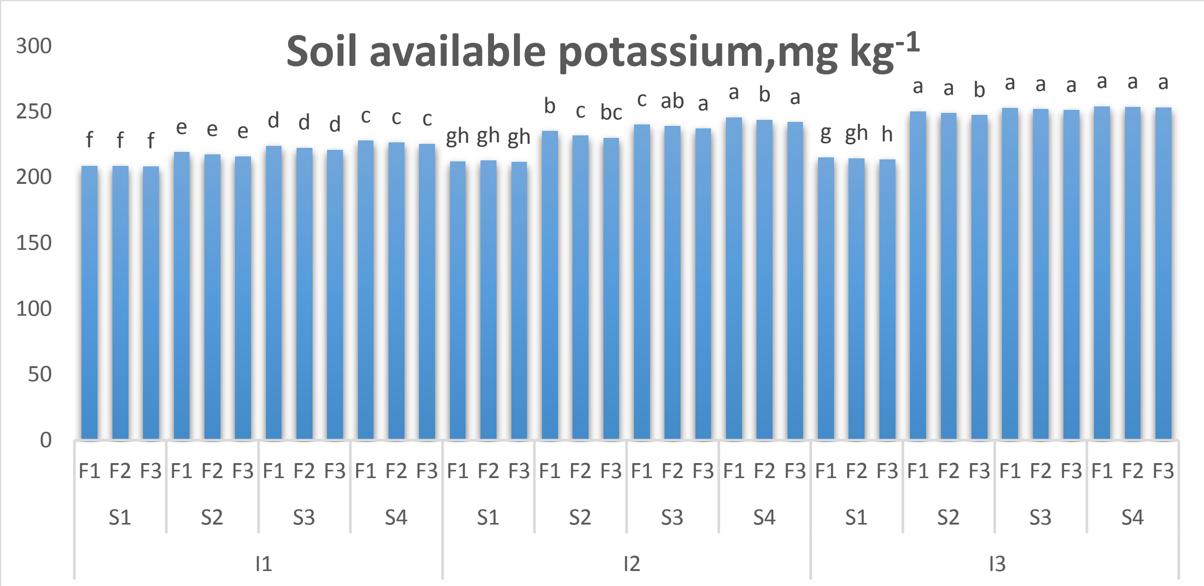


**Fig 3. Impact of the compost, biochar and sugar alcohols on soil available potassium after harvest during two successive seasons (2021-2022) (combined data over both seasons).**

$\mathbf{I_1}$: 100% of TFI; $\mathbf{I_2}$: 75% of TFI; $\mathbf{I_3}$: 50% of TFI; $\mathbf{S_1}$: without soil conditioner (control); $\mathbf{S_2}$: biochar alone; $\mathbf{S_3}$: compost alone; $\mathbf{S_4}$: biochar + compost; $\mathbf{F_1}$: without sugar alcohols (control); $\mathbf{F_2}$: glycerol and $\mathbf{F_3}$: Sorbitol.

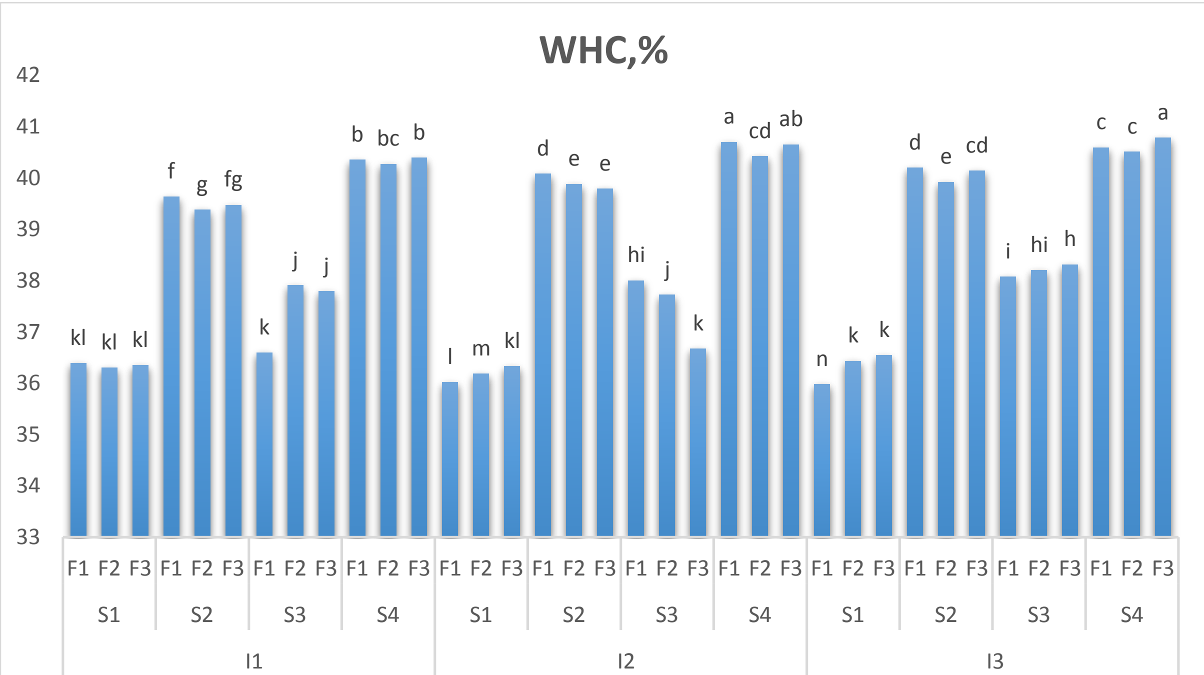


**Fig 4. Impact of the compost, biochar and sugar alcohols on soil water holding capacity (WHC) after harvest during two successive seasons (2021-2022) (combined data over both seasons).**

$\mathbf{I_1}$: 100% of TFI; $\mathbf{I_2}$: 75% of TFI; $\mathbf{I_3}$: 50% of TFI; $\mathbf{S_1}$: without soil conditioner (control); $\mathbf{S_2}$: biochar alone; $\mathbf{S_3}$: compost alone; $\mathbf{S_4}$: biochar + compost; $\mathbf{F_1}$: without sugar alcohols (control); $\mathbf{F_2}$: glycerol and $\mathbf{F_3}$: Sorbitol.

Biochar was more effective in holding irrigation water than compost due to the ability of biochar to hold irrigation water in its pores, hence it helped in declining the infiltration rate of the soil.

## 4. Discussion

Water is essential for the germination of maize seeds and growth. Water has various functions in plants include maintaining cell turgidity for structure and growth; comprising much of the living protoplasm in the cells; transporting nutrients and organic compounds throughout the plant; serving as a raw material for various chemical processes including photosynthesis and through transpiration, buffering the plant against water deficit and wide temperature fluctuations. It is known that reactive Oxygen Species (ROS) in higher plants tissues are produced due to water deficit stress.According to the obtained findings in this study, water deficit stress significantly reduced the growth performance, yield and yield-related characteristics of maize plants. In accordance with our findings,the plant's self-production from SOD, POD and CAT (unit $mg^{-1}$ $protein^{-1}$) had different trends in each studied period.It can be said that water deficit stress treatments (50 and 75 % of TFI, respectively) caused a raise in the contents of SOD, POD and CAT (unit $mg^{-1}$ $protein^{-1}$) in maize leaves at 60 days from sowing compared to the plants grown under traditional irrigation technique (100% of TFI), where a gradual decrease in irrigation requirements caused raising self-production gradually from these enzymatic antioxidants to increase tolerance water deficit stress, or in other words, it can be said that maize plants upregulated various scavenging mechanisms at the first half of the plant's life to suppression the water deficit stress-induced damage and alleviate the hazardous effect of ROS produced due to water deficit stress. Perhaps the ability of protoplasm manifested in this period in resisting the water deficit stress. On the contrary, the plant's self-production from SOD, POD and CAT (unit $mg^{-1}$ $protein^{-1}$) in its tissues declined with continued water-deficit stress for a long time (at a period of 90 days from sowing). Generally, it can be said that the negative effect of water deficit stress treatments (50 and 75 % of TFI, respectively) may occur physiological disorders in maize plants, which negatively affected the stomata opening, photosynthesis process and stomatal conductance. Thus, this negative effect is reflected in the plant growth performance, yield and its components (**Mosa and Ramadan, 2011 and El-Hadidi *etal.*, 2020).**

The improvement of plant performance, yield and its components of the plants grown under traditional irrigation technique (100% of TFI) could be due to sufficient both nutrients and irrigation water at the root zone of maize essential for both biological & physiological processes like cell division and elongation (**El-Sherpiny *et al.*, 2020)**.

The superiority of compost to biochar may be due to its ability to retain a large amount of Irrigation water for a long time and provide the soil with a large group of bacteria that have multiple important functions for the plant. More precisely, compost may provide the soil with nutrients and growth regulators as well as help to increase soil fertility and nutrient availability. Where this role may restore the vitality of the soil again. Moreover, compost may have influences on improving soil attributes due to its high content of organic matter and nutrients (**Ding *et al.*, 2021**).

On the other hand, the superiority of biochar to control treatment may be due to its ability to hold a high quantity of Irrigation water in its pores, thus biochar conditioner can retain more irrigation water in the root zone of maize plants to be uptaken as needed, thereby biochar help in tolerating the water deficit stress ((50 and 75 % of TFI, respectively) (**Fischer *et al.*, 2019 and Mosa *et al.*, 2020**).

Due to the advantages of both studied soil conditioners, the combination of biochar and compost makes the maize plant more able to tolerate water stress and maintain an acceptable yield (**Nadeem *et al.*, 2017**).Generally, it can be said that compost and biochar have vital role in preventing soil moisture losses **(Kim *et al.*, 2016; Rehman *et al.*, 2016 andCh'ng *et al.*, 2019).**

The foliar application of sorbitol and glycerol improved the growth of water deficit-stressed maize plants and this might be due to the effect of sugar alcohols on photosynthesis activity by protecting chlorophylls from the negative influence of drought stress *e.g.*, reactive oxygen species (ROS) (**Zhang *et al.*, 2015**). The catalytic role that appeared for both sorbitol and glycerol may be attributed that they have the ability to find various ways of being absorbed through the maize leaves through open stomata or pores. Currently, it is known that there are two main conductors within the higher plants for water and nutrients **(Moing, 2000),** which are wood and phloem and through them, the basic elements of the metabolic channels are connected, but the issue is that the main entrance to the wood is the growing tops of the roots, not the leaves **(Jain *et al.*, (2010).** As for the bark, the main artery for transporting elements, nothing is allowed to enter it **(Raoufi *et al.*, 2020).** The plant allows sugar alcohols to pass through the bark easily **(Li *et al.*, 2020).** All of this positively reflect on maintaining an acceptable yield under water deficit stress.

Finally, it can be noticed that the studied soil conditioners *i.e.*, compost and biochar (either solely or in combination), as well as the exogenous applications of sugar alcohols, led to a decline in the plant's self-production from the enzymatic antioxidants at 60 days from sowing as a result of raising plant resistance to the studied stress due to the investigated substances. Thus the plants don't need more self-production from the enzymatic antioxidants compared to the corresponding plants grown without any studied substances which possessed the highest plant's self-production from the enzymatic antioxidants. On the contrary, at the period of 90 days from sowing (growth advanced stage), the grown plants without the studied substances (soil conditioners and sugar alcohols) cannot continue producing these enzymatic antioxidants under water deficit treatments.

## 5. Conclusion

Obtained results of the current research work increase our knowledge regarding the efficacy of the combined effects of soil addition of biochar and compost as well as exogenous application of glycerol and sorbitol on maize plants grown under irrigation water deficit situations. Generally, it can be concluded that a combination of compost and biochar may hold enough amounts of Irrigation water and nutrients and release them as required by the maize plant, thus enhancing plant growth performance with the limited supply of Irrigation water. Also, sugar alcohols have a vital role in raising maize tolerance to water deficit conditions where sorbitol is more efficient than glycerol**.**

## Conflicts of interest

Authors have declared that no competing interests exist.

**Formatting of funding sources**: The research was funded by personal efforts of the authors.

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