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EGYPTIAN ACADEMIC JOURNAL OF
BIOLOGICAL SCIENCES
BOTANY

ISSN 2090-3812

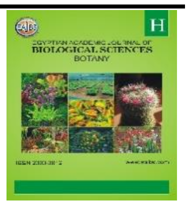
www.eajbs.com

Vol. 15 No.2 (2024)

Citation: Egypt. *Acad. J. Biolog. Sci.* (H. Botany) *Vol.15 (2) pp 57-64 (2024)*
DOI: 10.21608/EAJBSH.2024.394569

Egypt. Acad. Journal Biology. Sci., 15 (2):57-64 (2024)

Egyptian Academic Journal of Biological Sciences
H. Botany
ISSN 2090-3812
www.eajbsh.journals.ekb.eg.



Maize Growth in Relation to Biochar and Compost Application Under Irrigation Intervals

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ARTICLE INFO
Article History
Received:4/10/2024
Accepted:2/12/2024
Available:6/12/2024

***Keywords*:**
Mazie; growth; irrigation intervals; biochar; compost.

ABSTRACT

Two experiments will be conducted in the Alexandria Governorate, Egypt, in the 2023 and 2024 seasons to determine the response of the maize hybrid (SC 168) to soil amendment and irrigation treatments, as well as the interactions between them. The experiment used a split-plot design (SPD), with the main plot used for the three irrigation treatments and the four soil amendment treatments evenly, and randomly distributed among four replicates in the sub-plot throughout each of the two seasons. The results showed that irrigation treatments varied in all the examined characteristics, and these soil amendment treatments recorded different responses under irrigation treatments. For example, irrigating maize plants every 10 days, followed by a 15-day interval, produced the highest values of maize when compared to a 20-day interval, but using compost or biochar increased the growth of maize in both seasons under conditions that were like those used in the study.

INTRODUCTION

Maize (Zea mays L.), a grain crop, is cultivated across Egypt's diverse agro-ecological zones, where it thrives in a range of environmental conditions. After wheat and rice, maize is Egypt's third-most important staple food crop in terms of land area and production. In Egypt, maize cultivation occupies about 888329 hectares, representing 25.17% of the total cultivated agricultural area. The crop yields an average of 7.80 tons per hectare. Maize represents approximately 21.90% of the cereals produced worldwide(FAO, 2023).

Maize is one of the most prevalent and economically significant crops in the Poaceae family. It is a promising candidate for vehicle fuel and is utilized in the treatment of various diseases, dye production, the production of biogas, and the food industry for both humans and animals. Improved farming techniques, technological advancements, and the use of high-yielding, contemporary maize hybrids that are more resilient to salinity and water stressors can all be used to increase crop productivity. This will help to close the gap between

DOI: 10.21608/EAJBSH.2024.394569

production and consumption and raise grain yield per unit area of agricultural land (Sangoi, 2001).

According to Er-Raki *et al.* (2007), in certain areas when drought is a common occurrence, a crop's ability to receive water is a major factor in determining its yield. The increasing global population has rise to many challenges for many countries, particularly regarding food security and production (RNRC, 2015). Maintaining crop growth and productivity in a sustainable manner requires plants to react to the negative impacts of abiotic stress. Soil management options that improve fertility, water availability, and the root zone can serve as effective drought mitigation measures in both irrigated and non-irrigated contexts (Phillips *et al.*, 2020).

Maize crops showed greater susceptibility to water stress than one in soil treated without biochar, but less so in soil treated with biochar (Babalola *et al*., 2022). Salt negatively impacts maize physiology, affecting respiration, photosynthesis, transpiration, and seed germination, leading to reduced growth and yield. Nonetheless, salinized maize demonstrates varied physiological responses depending on development stages and genetics, which could be utilized for drought mitigation (Iqbal *et al*., 2020 and Sabagh *et al*., 2021).

Incorporating soil additives such as biochar is one of the most feasible and safest ways to mitigate the adverse effects of stress on soil water content, plant growth. Although, the concept of incorporating biochar to soil is not new, it has recently gained significant attention due to its potential to increase agricultural productivity, mitigate climate change, enhance soil fertility, and conserve water (Alotaibi and Schoenau, 2019).

The porous structure and large surface area of biochar facilitate the gradual and controlled delivery of nutrients and water to the plant, enabling the formation of cohesion and adhesion forces (Dempster *et al*., 2012). Oxygen functional groups found on the surface of biochar aid in preserving higher soil moisture levels and encourage water usage efficiency (Suliman *et al*., 2017). Biochar soil amendment has been proposed as a drought stress mitigation strategy for many plants (Batool *et al*., 2015). Biochar enhances photosynthesis and water retention, improving soil quality and plant drought tolerance, making it a potential alternative to synthetic fertilizers in agriculture (Arthur *et al*., 2020).To improve plant growth, development and production in nutrient-deficient soils, biochar has been used extensively (Vaccari *et al*., 2011; Rogovska *et al*., 2014). Additionally, Uzoma *et al*. (2011) found that adding cow dung biochar to the soil significantly increased maize output and nutrient absorption. Bruun *et al*. (2014) demonstrated a similar pattern in which biochar enhanced root penetration and density while also increasing water retention.

Applying biochar to soil improves growth, root development, and soil water retention (Abiven *et al*., 2015). Applying biochar is effective at changing the properties of the soil, which eventually leads to improved plant growth (Cao *et al*., 2014). Composting can enhance both the chemical and physical characteristics of soil, including bulk density, porosity, water permeability, and hydraulic conductivity. This might ultimately lead to higher crop growth (Hussain *et al*., 2001). In another experiment, drought led to a 76% decrease in the control group's soil water. While 3% biochar reduced plant height and leaf count during stem elongation, these traits stabilized during blooming. Biochar at 2% and 3% improved soil water retention, preserving transpiration, photosynthesis, stomatal conductance, and leaf water potential. On average, 2% biochar boosted biomass in drought-treated plants, whereas 1% and 3% reduced it. Overall, biochar lowered biomass by 1% and 2%, and raised it by 3%. However, under irrigation, biochar reduces plant and maize biomass (Ahmed *et al*., 2016).

The objectives of this study were therefore to: (1) evaluate the effects of irrigation schedules, compost, and biochar treatments on maize growth; (2) explore the interactions between different irrigation schedules, compost, and biochar applications on maize growth; and (3) determine which treatments are most appropriate for farmers to implement.

MATERIALS AND METHODS

1- Study Area:

In the growing seasons of 2023 and 2024, two field studies were carried out in the Abees Region, Alexandria Governorate, Egypt, to investigate the effects of biochar application, compost, and irrigation treatments on certain growth parameters of maize hybrids (SC 168).

The hydrometer method was used to determine the soil texture (Topp *et al.*, 1993). The modified Walkey-Black approach, as recommended by Nelson and Sommers (1996), was utilized to determine the number of organic materials. The method of determining the available potassium (K) and phosphorus (P) was done according to the approach provided by Sims, 2000. The nitrogen content was calculated using the approach described by Jackson (1973).**Table (1),** presents some physical and chemical assessments of the testing site.

Table 1. Some physical and chemical properties of the experimental soil in both seasons.

Soil Properties	**Seasons**	
	2023	**2024**
	Mechanical analysis	
Sand	16.00	15.00
Silt	39.70	40.50
Clay	44.30	44.50
Soil texture	Clay loam	Clay loam
p^H (1:1)	8.20	8.15
	Chemical properties	
EC (1:1) dS/m	3.60	3.70
	Soluble cations (1:2) (cmol/kg soil)	
K^+	1.55	1.60
Ca^{++}	14.17	14.20
Mg^{++}	10.34	10.40
Na^+	14.55	15.00
	Soluble anions (1:2) (cmol/kg soil)	
$CO^-_3 + HCO^-_3$	2.90	3.00
CL^-	21.00	21.50
SO^-_4	16.70	17.01
Calcium carbonate (%)	6.20	6.40
Total N (%)	1.20	1.35
P (mg/kg)	3.40	3.35
Organic matter	1.40	1.60

2- Experimental Design and Crop Management:

Split plot design (SPD) was used for the experiment; the main plots were occupied by irrigated treatments at treatments of 10, 15, and 20 days, and the four soil amendments (control, compost, biochar, and compost + biochar) were distributed at random within the sub- plots in each of the four replicates over the course of the two seasons..

Soil amendments which namely (untreated (No addition), compost at the rate of 3.6 t/ha, biochar at the rate of 3.6 t/ha, and compost at the rate of 2.4 t/ha + biochar at the rate of 2.4 t/ha).

Single cross, S.S. 168, which is a hybrid variety of yellow maize, was officially acquired from the Egyptian Ministry of Agriculture. This acquisition took place before the planting phases that occurred on two distinct dates: the first planting was carried out on May 15, 2023, followed by a second planting on April 25, 2024. As the plants developed and reached an age of 21 days, measures were taken to enhance their growth. At this point, the plants were carefully trimmed to ensure that only one healthy plant remained per hill, promoting better growth and resource allocation. Additionally, the field received adequate watering to sustain the plants' needs. On the same day that the seeds were planted, two specific herbicide treatments were applied to ensure the establishment of the crop and manage any weed competition. The herbicide treatments consisted of Gesaprim at a concentration of 80% WP, applied at a rate of 1.8 kg per hectare, along with Harness, which is an 84% EC formulation, administered at a rate of 2.5 liters per hectare. These treatments were designed to provide effective weed control and support the healthy development of the maize crop throughout its growth cycle.

Additional agricultural practices were implemented in compliance with the guidelines provided by Egypt's Ministry of Agriculture.

3-Application of Fertilizers:

Potassium sulphate (K_2SO_4) was added at a rate of 120 kg/ha during the soil preparation in both seasons. Prior to planting, a calcium super phosphate (15.5% P2O5) phosphorus fertilizer (60 kg P_2O_5/ha) was broadcasted on. Ammonium nitrate (NH_4NO_3 - 33.50 N%) was used as the N source for the two seasons at a rate of "288 kg N/ha" and in two equal doses, one at sowing and the other one after 21 days.

4-The Studied Characters:

***Growth characters**:*

1. Plant height (cm) was measured (as an average of five random plants from each subplot) from the soil surface to above the plant at harvest (120 days after sowing).
2. Crop growth rate (CGR) g/week/m^2 at the two growth periods (45 - 60 and 60 – 75 days after sowing (DAS)).
3. Leaf area index (LAI): expresses as ratio of leaf area to the ground area occupied by the crop plants.
   LAI was calculated at 90 days after sowing (DAS) according to Radford (1967).
4. Total chlorophyll content (SPAD): determined by chlorophyll meter apparatus using ten random leaves taken from each sub-plot at (90 DAS), according to the method described by Minolta Camera (1989).
5. Ear height (cm)

5-Statistical Analysis:

All collected information was analyzed using the variance analysis technique described by Gomez and Gomez (1984). CoStat software was utilized for all statistical analyses (CoStat, 2005), and the least significant difference (LSD) at the 0.05 probability level was employed to compare treatment means.

RESULTS AND DISCUSSION

The results presented in Tables 2 and 3, indicate that irrigation scheduling, the application of soil amendments, and their interaction had a significant impact on all the studied traits, including plant height (cm), crop growth rate during the two growth periods, leaf area index (LAI), chlorophyll reading (SPAD unit), and ear height (cm), on yellow maize hybrids SC 168 in 2023 and 2024 seasons.

The impact of irrigation treatments on maize growth parameters, the findings, as presented in Tables 2 and 3, showed that plant height (cm), crop growth rate during the two growth periods (45–60 and 60–75 days after days; DAS), leaf area index (LAI), chlorophyll reading (SPAD unit), and ear height (cm) were highest in maize plants irrigated every 10 days. The second interval, which was irrigation every 15 days, resulted in the second-highest values while the third interval, irrigation every 20 days, gave the lowest ones. These findings are in agreement with those reported by Mohammadai and Shams (2012); Abdel Halim and

Abd El-Razek (2013); Shen *et al.* (2020); Halli *et al.* (2021) who reported that irrigation treatments had a substantial impact on growth for corn.

Table 2. The effect of irrigation intervals, soil amendments and their interaction on plant height, ear height and ear length of maize in both seasons.

Character	Irrigation intervals	Season 2023					Season 2024				
		Soil amendments					Soil amendments				
		Control	Compost	Biochar	Compost + Biochar	Average (A)	Control	Compost	Biochar	Compost + Biochar	Average (A)
Plant height (cm)	Every 10 days	237.00	283.00	282.38	263.88	266.56	228.38	273.25	272.75	255.88	257.56
	Every 15 days	252.25	264.75	268.00	257.75	260.69	243.63	255.43	258.75	248.25	251.51
	Every 20 days	232.25	239.25	253.75	255.25	245.13	226.75	231.75	243.50	244.13	236.53
	Average (B)	240.50	262.33	268.04	258.96		232.92	253.48	258.33	249.42	
	LSD at 0.05	A=9.92	B= 7.08	AB= 12.26			A= 10.31	B= 6.66	AB=11.54		
Crop Growth rate (CGR – 45 -60 day after sowing)	Every 10 days	2.32	3.23	2.92	3.22	2.92	2.56	3.45	3.14	3.42	3.14
	Every 15 days	2.22	3.02	3.49	2.78	2.88	2.46	3.24	3.71	2.99	3.10
	Every 20 days	1.74	2.14	2.83	2.84	2.39	1.97	2.38	3.03	3.06	2.61
	Average (B)	2.10	2.80	3.08	2.95		2.33	3.02	3.30	3.16	
	LSD at 0.05	A= 0.32	B=0.35	AB= 0.61			A= 0.29	B= 0.35	AB= 0.61		
Crop Growth rate (CGR – 45 -60 day after sowing)	Every 10 days	2.70	3.61	3.26	3.54	3.28	2.95	3.89	3.51	3.92	3.57
	Every 15 days	2.58	3.36	3.82	3.14	3.23	2.84	3.61	4.07	3.42	3.49
	Every 20 days	2.16	2.52	3.20	3.21	2.77	2.41	2.77	3.51	3.46	3.04
	Average (B)	2.48	3.16	3.43	3.30		2.73	3.42	3.69	3.60	
	LSD at 0.05	A= 0.28	B= 0.33	AB= 0.57			A=0.25	B= 0.32	AB= 0.56		

Table 3. The effect of irrigation intervals, soil amendments and their interaction on growth characteristics of maize in both seasons.

Character	Irrigation intervals	Season 2023					Season 2024				
		Soil amendments					Soil amendments				
		Control	Compost	Biochar	Compost + Biochar	Average (A)	Control	Compost	Biochar	Compost + Biochar	Average (A)
LAI	Every 10 days	3.41	4.41	4.74	4.68	4.31	3.49	4.42	4.76	4.73	4.35
	Every 15 days	3.24	4.36	4.62	4.25	4.12	3.30	4.31	4.65	4.32	4.14
	Every 20 days	2.85	3.59	3.85	3.93	3.55	3.10	3.63	3.79	3.64	3.54
	Average (B)	3.17	4.12	4.40	4.29		3.30	4.12	4.40	4.23	
LSD at 0.05		A= 0.12	B= 0.20	AB= 0.35			A= 0.16	B= 0.20	AB= 0.35		
Chlorophyll content	Every 10 days	41.75	45.88	48.15	48.05	45.96	41.75	45.88	48.15	48.05	45.96
	Every 15 days	38.70	46.13	46.10	42.18	43.28	38.70	46.13	46.10	42.18	43.28
	Every 20 days	32.38	35.58	43.10	41.75	38.20	32.38	35.58	43.10	41.75	38.20
	Average (B)	37.61	42.53	45.78	43.99		37.61	42.53	45.78	43.99	
	LSD at 0.05	A= 4.19	B= 2.05	AB= 3.55			A= 3.86	B= 2.03	AB= 3.51		
Ear height (cm)	Every 10 days	137.75	146.00	149.50	151.75	146.25	133.63	140.25	144.75	147.00	141.41
	Every 15 days	132.50	146.50	142.25	138.00	139.81	129.00	143.00	138.75	136.50	136.81
	Every 20 days	106.13	122.25	120.50	125.75	118.66	103.25	118.25	116.50	121.25	114.81
	Average (B)	125.46	138.25	137.42	138.50		121.96	133.83	133.33	134.92	
	LSD at 0.05	A= 9.50	B= 5.97	AB= 10.34			A= 9.30	B= 8.06	AB= 9.29		

The results presented in Tables 2 and 3, illustrate the impact of soil amendments, including compost, biochar, or a combination of the two, demonstrated that applying compost, biochar, individually or in combination with other soil amendments recorded the maximum values of all the studied growth characteristics of maize in both seasons, with the highest values obtained with biochar and the mixture of compost + biochar application, respectively, in comparison to the control treatment.

The incorporation of biochar into the soil significantly enhanced several important factors, including soil moisture levels, potassium (K) availability, and the presence of plant-available phosphorus. Each of these elements demonstrated a strong and positive correlation with the above-ground biomass produced by maize plants, indicating that the benefits of biochar positively influence the growth and development of maize crops. This improvement in nutrient availability and moisture retention is crucial for optimizing the biomass yield in maize cultivation (Pandit *et al*., 2018). Biochar has recently been shown to form organic pore coatings that improve water retention (Hagemann *et al*., 2017), by reducing pore space (lowering capillary rise), and boosting hydrophilicity. While, Benkova *et al.* (2023) reported that whereas sewage sludge and compost both enhanced soil available K and P, soil available N was only raised by compost. These results are consistent with those found by Vaccari *et al*. (2011); Bruun *et al*. (2014); Rogovska *et al*., (2014); Ibrahim and El-Kader (2015); Coulibaly *et al*. (2019); Arthur *et al.* (2020).

The interaction effect between the two factors is displayed in Tables 2 and 3, which show that the highest values of maize growth characteristics were recorded when compost or biochar was used which enhanced plants tolerance to increasing irrigation treatments. The application of compost demonstrated a similar trend under the conditions, while the application of a compost and biochar mixture yielded comparable results. The application of biochar in conjunction with irrigation treatments of 15 days resulted in enhanced maize growth characteristics across both seasons.

CONCLUSION

This study reveals that soil application of biochar or compost or the combination of them can result in high maize growth of SC 168 hybrid under different irrigation treatments especially irrigation every 10 or 15 days. In conclusion, it is viable and sustainable to achieve high growth characteristics under normal irrigation and irrigated plants every 15 days in the Alexandria maize region in Egypt.

Declarations:

Ethical Approval: No animal model(s) or human subjects were recruited directly for the current study. Consequently, no ethical considerations are necessary.

Conflict of interest: The authors declare no conflict of interest.

Authors Contributions: I hereby verify that all authors mentioned on the title page have made substantial contributions to the conception and design of the study, have thoroughly reviewed the manuscript, confirm the accuracy and authenticity of the data and its interpretation, and consent to its submission.

Funding: The author(s) received no specific funding for this work.

Availability of Data and Materials: All datasets analysed and described during the present study are available from the corresponding author upon reasonable request.

Acknowledgements: I would like to express my sincere gratitude to the Plant Production Department, Facultuy of Agriculture, Saba Basha, Alexandria Univesrty, Alexandria**,** Egypt, for their invaluable support and guidance throughout the course of this research. Their expertise, resources, and encouragement have been instrumental in the successful completion of this study.

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