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EXPLORING THE SYNERGISTIC EFFECT OF ANIMAL MANURE AND BIOCHAR TO IMPROVE MAIZE GROWTH AND PRODUCTIVITY UNDER WATER DEFICIT CONDITION

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ABSTRACT

Drought stress is a most imperative environmental factor that often constrains crop production worldwide. The less availability of organic matter in soil and less available water are the major ecological issues to the world food security. In the current investigation, a pot experiment was conducted to the effect of animal manure and biochar on morpho-physiological and quality parameters of maize under well water and water deficit conditions. The maize hybrid 30-32-30 was grown in pots by using CRD factorial arrangement. The experiment was comprised of four treatments and five replications under both well water and water deficit. Treatments were consisting of sole and combined application of animal manure and biochar @ 10 t ha^{-1} while the combination have 1:1 ratio under both water regimes. Pots under well water were irrigated at 100% FC, while water deficit were irrigated on bases of 50% FC. After about 2 months of sowing, data related to its morpho-physiological and quality attributes were recorded. The observations revealed that deficit irrigation negatively affects the growth and quality of maize. The loss in shoot fresh and dry biomass was 38.5 and 42.5% under deficit irrigation as compared to well-watered control, however, combined applied animal manure and biochar improved it 48.5 and 71.3%, respectively. Similarly, root fresh and dry biomass were decreased to 44.8 and 86.4% by deficit irrigation, therefore, maximum improvement i.e. 68.8 and 96.4% was observed under the combination of organic matter and biochar. However, combined application of animal manure and biochar also best improved stem girth (67%), stem length (35%), no. of leaves $plant^{-1}$ (67.7%), no. of nodes $plant^{-1}$ (75%), chlorophyll contents (16.6%), Water use efficiency (93.3%) and photosynthetic rate (45%) as compare to control treatment, under water deficit conditions, showing that the combined application of amendments is more useful for maize growth than the sole application. However, the stomatal conductance and transpiration rate were reduced to 9.3 and 17.1% under combined use of animal manure and biochar in deficit irrigation treatments. Therefore, it is concluded that maize production can be improved by the combined use of biochar and animal manure under deficit irrigation, however detailed field research is required before wide applications in the field.

Keywords: Animal Manure, Biochar, Maize production, Soil health and Water stress

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1. INTRODUCTION

Maize (Zea mays L.) is essential staple food and an imperative cereal crop that fulfill the food requirement of population all over the world, is the third most widely grown crop in Pakistan, following wheat and rice (Ahmed et al., 2018). Corn ethanol, corn starch, corn oil and corn flakes are the products obtained from the maize grains (Košutić et al., 2023). In Pakistan, total cultivated area of maize is about 1.318 million hectares. However, contributes 0.5% to the GDP, with annual grain production of 5.70 million tons (Nabeel et al., 2018). The Maize grain is composed of 72% starch, 10% protein, 3% sugar, 8.5% fiber, 1.7% ash, and 4.8% oil (Aslam et al., 2020). Due to climatic changes and socio-political issues, Pakistan is facing the issue of low availability of

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water, which is a great threat to agriculture sector as well as humans to achieve the good yield of the desirable crops. So, it is necessary to enhance the water use efficiency to get the better production of maize under deficit irrigations. (Yu et al., 2020).

Among the environmental factors, drought is one of the very important abiotic factors which harmfully affects plant yield and production (Zafar et al., 2023). Effects of deficit irrigation on plants have been observed for a long time and the water stress induced by low water supply have been studied from the plant population level to molecular level (Huang et al., 2024). However, Water stress involved moderate water loss, also causing stomatal closure and restricted gas exchange, which disrupted metabolism, damage cell structure, and halt enzyme-catalyzed reactions (Nazim et al., 2023). It is noticeable by reduced water content, lowered leaf water potential, turgor loss, stomatal closure, and decreased cell enlargement and growth (Nazim et al., 2021). Under Water stress, available water cannot fulfill the demand of plants for the long time period that increase stress on plants, which disturbs the rate of gaseous exchange and stomatal closure in plants and causes the interruption of cell structure and metabolism, as a result of that causes the end of enzymatic reactions (Nazim et al., 2024).

Drought stress causes low turgidity with reduced leaf water potential, disturbance in cell enlargement, lowers down the plant water content, plant growth and ultimately stomatal closure which slow down the photosynthetic rate that results as the death of plant (Lamaizi et al., 2023). Due to drought stress, plant uptakes less water, due to which tissue's water contents also decrease, as a result plant turgor pressure is reduced which causes disruption in cell elongation (Abbas et al., 2023). Deficit irrigation affected the plant growth badly by reducing leaf surface area, rate of transpiration, stomatal closure rate, net CO_2 assimilation rate, nutrient imbalance and reduction in chlorophyll content (Huang et al., 2022). Organic materials such as farmyard manure have traditionally been used by farmers (Lim et al., 2015). It provides all major nutrients (N, P, K, Ca, Mg, S,) necessary for plant growth, as well as micronutrients (Fe, Mn, Cu and Zn) and nutrient uptake (Meena et al., 2018).

Biochar is a carbon containing material which is obtained from pyrolysis of organic residues. It is a carbon-rich product created by heating biomass, such as wood, manure, or crop residues, in a closed container with minimal or no oxygen (Allakonon et al., 2022). Biochar is derived from the burning of plant material in absence of oxygen (Pyrolysis), and it has many positive effects on landscape ecology (Zahra et al., 2021). The effect of biochar on crop production depends on soil properties, nature of biochar, prevailing climatic conditions and crop husbandry (Van Zwieten et al., 2010). It is extremely recalcitrant (Cheng et al., 2006) due to its condensed aromatic ring structure (Laskari et al., 2022), with an estimated mean dwelling time ranging as of 90 to 1600 years (Tomczyk et al., 2020). Its basic characteristic, influenced by the pyrolysis process and treatment (Lee et al., 2010), its cation exchange capacity attributed to a large negatively charged surface area (Ngo et al., 2023). Additionally, biochar characteristics are determined by the category of feedstock used. Biochar holds some essential plant nutrients that enhance maize growth. Maize yield production and water-use-efficiency (WUE) increased by 50 to 100%, when the biochar applied rate was increased from 5 to 20 t ha^{-1} (Uzoma et al., 2011). The application of biochar to agricultural lands is another beneficial practice to improve soil fertility as well as crop production (Major et al., 2010). Biochar as a material is resistant to microbial decomposition and assures long term advantages for soil health improvement (Steiner et al., 2007).

It improves crop production by improving nutrient availability, nutrient retention, and water holding capacity, bulk density, soil permeability and other biological characteristics of soils (Kapoor et al., 2022). Therefore, due to the high rate of decomposition of organic manure, the use of biochar in soils can provide benefits on sustainable basis (Wu et al., 2023). Biochar is more suitable source of soil organic carbon in contrast to FYM and corn stover waste which are susceptible to high rate of decomposition (Torn et al., 2005). Hence, the main emphasize of this study is to evaluate the effects of alone and combined application of animal manure and biochar under deficit irrigation and to improve maize production under deficit irrigation.

2. MATERIALS AND METHODS

An experiment was conducted in Experimental research area of MNS-University of Agriculture, Multan, Pakistan. The impact of sole and combined application of animal manure and biochar on maize morphological, physiological and quality attributes were evaluated under well water and water deficit in plastic pots filled with 7 kg soil. The soil used for the experiment was silty loam, PH 7.6, organic matter 0.57 and 40% saturation percentage.

2.1 Treatment Plan and Applications

Maize hybrid "Maize 30-32-30" was sown in the pots having 7 kg soil. The experimental plan included the four treatments and five replications of each treatment under both well water and water deficit by using CRD (Complete Randomized Design) factorial design. Four treatments were T_1 = control (no organic amendment), T_2 = animal manure at the rate of 10 t ha^{-1}, T3 = biochar at the rate of 10 t ha^{-1}, T4 = combination of animal manure and biochar at the rate of 10 t ha^{-1} (1:1). The population of three seedlings were maintained in each pot after the germination.

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Irrigations were maintained after one week of germination, based on the field capacity as deficit irrigations were on 50% FC while well water irrigations on 100% FC of the soil. Phosphorus and Potassium fertilizer were applied before sowing and nitrogenous fertilizer was added after germination in two splits at rate of 120-60-60 kg ha^{-1}. Animal manure used in this experiment was took from the cattle farm and biochar produced by the pyrolysis of apple tree branches was imported from Germany. A separate set of 8 pots individually having the same treatments were arranged to check the moisture level with one-day interval, for the FC maintenance. Tap water was used for the irrigations as per requirements upto 60 days after the sowing. Plant analyses were also done before and after the harvesting of plants to record the growth, physico-biochemical and quality parameters of the maize crop.

2.2 Plant Analysis

After the 55 days of the sowing, plant growth attributes like plant height $plant^{-1}$ (cm), number of leaves $plant^{-1}$, stem diameter $plant^{-1}$ (cm/mm) and physiological attributes like chlorophyll contents by using SPAD meter, transpiration rate, stomatal conductance (mmol/m2/s), and photosynthetic rate (umol/m2/s) by using portable infrared gas analyzer system (IRGA) were recorded. After the harvesting, shoot and root fresh weight per plant (g) was recorded with the help of weighing balance. After that, these plant samples were oven dried at 72ºC for 24 hours. After drying till constant weight of root and shoot (g) was again recorded. Plant quality parameters like nitrogen (%) and protein contents (%) were also determined by using Kjeldhal apparatus, followed by digestion, titration and distillation revealed by Storvick (1950).

2.3 Statistical Analysis

The data was statistically analyzed using a Completely Randomized Design (CRD) with a factorial arrangement, and treatment means were compared using the LSD test (Steel et al., 1997).

3. RESULTS

2.4 Growth and Phonological Parameters

The sole and combined application of animal manure and biochar under well water and deficit irrigation on shoot and root fresh as well as dry biomass of maize is shown in Table 1. Fresh and dry biomass of maize shoot and root was maximum recorded by the combined application of animal manure and biochar (1:1) under both well water and deficit irrigation (Fig. 2). However, deficit irrigation significantly reduced the fresh and dry biomass. However, the interactive effect of water and applied amendments is non-significant for these parameters (Table 1). Whereas, deficit irrigation significantly reduced the morphological attributes of maize, which were improved by the organic amendments.

Table 1: Effect of sole and combined application of animal manure and biochar on shoot and root fresh and dry biomass of maize under well water and deficit irrigation.

Treatment	Shoot fresh biomass (g)		Shoot dry biomass (g)		Root fresh biomass (g)		Root dry biomass (g)	
	W.W	D.I	W.W	D.I	W.W	D.I	W.W	D.I
Control	43	26.4	21.2	12.2	19.3	10.7	7.3	3.4
Animal manure	45.8	37.4	23	17.6	20.5	11.1	9.8	4.3
Biochar	49.2	36.8	22.2	17.6	21.4	13.8	9.9	4.7
A.M + Biochar	55	39.2	25.8	21	24.6	18	10.7	6.7
P>0.005	0.872		0.73		0.33		0.43	

Fig. 1: Effect of combined application of animal manure & biochar on maize growth under well-watered and deficit irrigation condition.

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An almost similar effect was observed for shoot length plant^{-1} (cm), number of leaves plamt^{-1}, number of nodes plamt^{-1} and stem diameter of maize plant^{-1} under well water and deficit irrigation (Table 2). However, sole application of organic amendments i.e. animal manure and biochar also improved the morphological parameters of maize, as compared to control under both well water and deficit irrigation.

Table 2: Effect of sole and combined application of animal manure and biochar on shoot length, shoot diameter, number of leaves and number of nodes of maize under well water and deficit irrigation.

Treatment	Shoot length (cm)		Shoot diameter (cm)		No. of nodes plant^{-1}		No. of leaves plant^{-1}	
	W.W	D.I	W.W	D.I	W.W	D.I	W.W	D.I
Control	84	67.1	1.6	0.70	2.7	2.4	8.6	6.8
Animal manure	89.6	84	1.5	1.82	3.2	3.2	9.4	8
Biochar	99.3	86.2	1.95	1.84	4.2	3.4	11.6	10
A.M + Biochar	100.7	90.7	3.02	2.12	4.5	4.2	12.8	11.4
P>0.005	0.24		0.00		0.30		0.92	

2.5 Physiological and Quality Parameters

On the other hand, quality parameter i.e. nitrogen contents (%) of maize also reduced significantly by deficit irrigation. But the combination of animal manure and biochar improved it best as compared to other treatments under both water regimes (Fig. 2). Similar effects of water regimes and applied amendments were found for protein contents of maize (Fig. 3). However, the interactive effect of water and amendments for quality parameters is significant ($p \leq 0.05$).

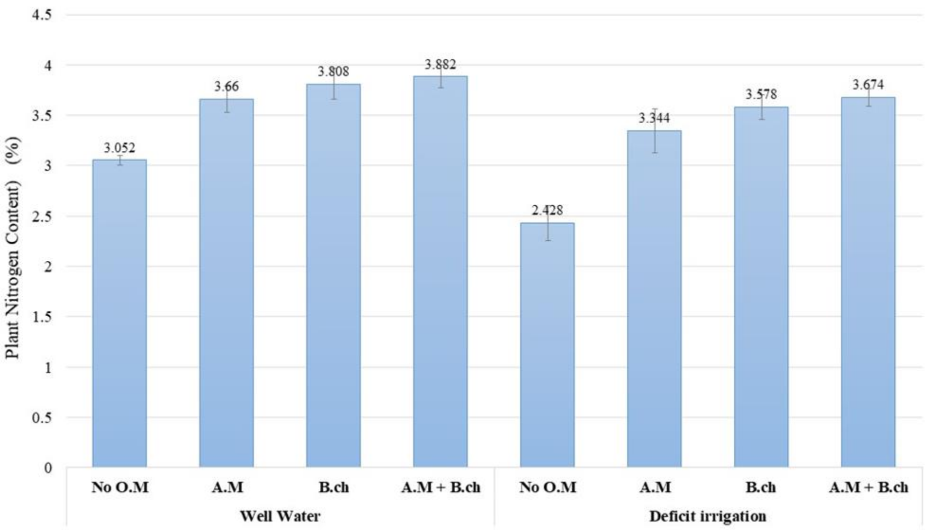

Fig. 2: Effect of sole and combined application of animal manure and biochar on nitrogen contents (%) of maize under well water and deficit irrigation

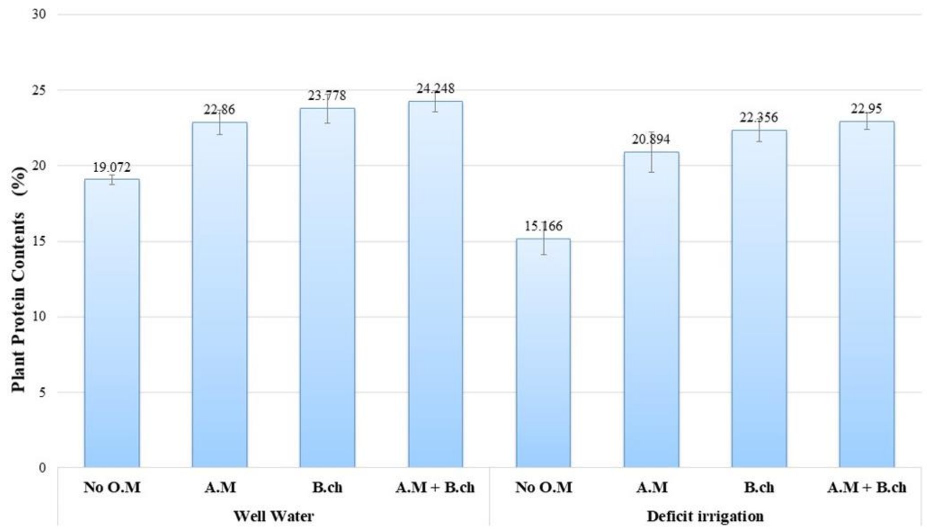

Fig. 3: Effect of sole and combined application of animal manure and biochar on protein contents (%) of maize under well water and deficit irrigation.

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In physiological parameters, it is claimed that deficit irrigation negatively affects the morphology of maize, but chlorophyll contents (SPAD value) significantly increased under stress conditions. However, applied amendments decreased the SPAD value (Table 3). However, stomatal conductance (*gs*), transpiration (*Tr*) and photosynthetic (*Pn*) rate were also badly affected by the deficit irrigation. However, stomatal conductance (*gs*) and photosynthetic rate (*Pn)* were positively affected by the combination of animal manure and biochar. Whereas transpiration rate was best affected under the sole application of animal manure, as compare to other treatments, under both well water and deficit irrigation (Table 3). Physiological water use efficiency was best observed by the sole application of animal manure under well water conditions. While under deficit irrigation, maximum physiological water use efficiency was observed by the sole application of biochar (Fig. 4).

Table 3: Effect of sole and combined application of animal manure and biochar on chlorophyll contents, photosynthetic rate, transpiration rate and stomatal conductance of maize under well water and deficit irrigation.

Treatment	Chlorophyll contents (SPAD value)		Photosynthetic rate (μmol CO_2 m^{-2} s^{-1})		Transpiration rate (mmol H_2O m^{-2} s^{-1})		Stomatal conductance (mmol H_2O m^{-2} s^{-1})	
	W.W	D.I	W.W	D.I	W.W	D.I	W.W	D.I
Control	30	34	21.9	19.9	7.4	6.2	225	203
Animal manure	32	38	28.8	23.95	5.2	5.1	163	156
Biochar	32.5	39	28.3	23.87	6.0	5.17	184	157
A.M + Biochar	35	43.5	31.9	28.7	5.6	5.2	188	184
P> 0.005	0.41		0.80		0.15		0.88	

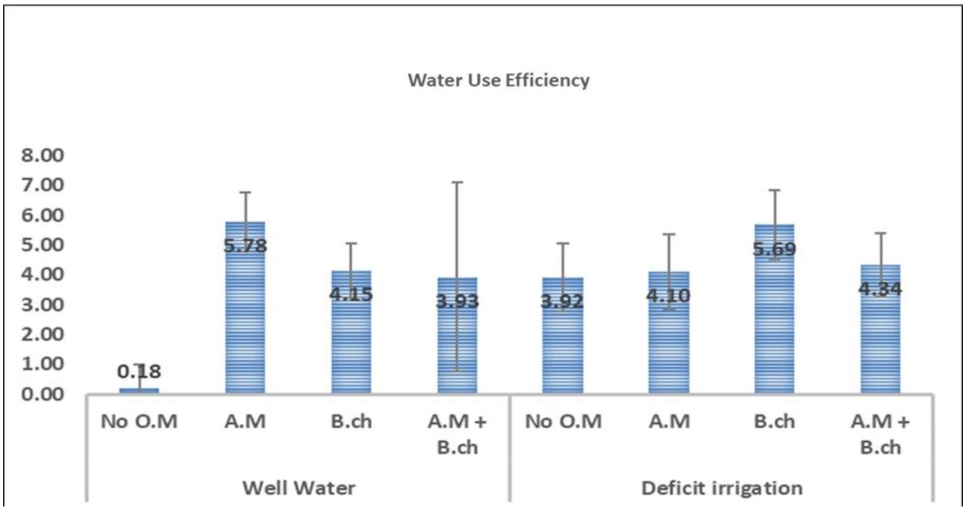

Fig. 4: Effect of sole and combined application of animal manure and biochar on physiological water use efficiency (%) of maize under well water and deficit irrigation.

4. DISCUSSION

Our findings state that deficit irrigation has reduced growth and quality of maize. The application of organic manure and biochar has variable effects on plant growth under well water and water deficit conditions. Hence, it can be suggested that limited water availability under deficit irrigation had adverse effect on shoot fresh weight of maize, as it is common response that drought stress exert a negative effect on the biomass production of the plants (Alfadil et al., 2021). However, the reduction in SFW of maize under deficit irrigation treatment was less (28.7%) than reduction in well water (38.3%) where animal manure and Biochar was applied in 1:1 ratio. Kage et al. (2004) also stated that under deficit irrigation stress, plant production is directly linked with dry biomass production and its distribution in plants.

Our results are supported by Efthimiadou et al. (2010), who reported that the lowest dry weight was observed in the control plots (5453kg.ha^{-1}), while the highest dry weight was achieved with double cow manure and double barley (mulch and fertilizer) treatments compared to the control. From the critical analysis data, the effects of deficit water stress can be reduced by the combined application of animal manure and biochar on maize growth (shoot & root fresh weight, dry biomass weight, shoot length, No. of leaves and nodes), physiology and quality of green biomass and organic amendments significantly improved the physiological water use efficiency of maize crop. Xiao and Pignatello (2015) also found similar results, observed that biochar amendment significantly impacted the growth and weight of maize roots at various stages of crop development, as evidenced by increased root weight density as well as root length density.

Similar observations were found by Uzoma et al. (2011) reported that integrated nitrogen management had great effect on dry biomass production of maize and maize yield was also improved by 32% as compared to control). However, it can be said that maize is the nutrient-challenging crop and observed that plant height, stem diameter, and leaf area decreased significantly with increasing water stress (Anjum et al., 2011). Our results align with Farhad et al. (2011), who also observed an increase in plant height with the application of organic manure, such as poultry compost. Cell growth is considered one of the most drought-sensitive physiological processes due to the reduction in turgor pressure (Zafar et al., 2022a, b). So, it was suggested that stomata show good response to chemical signals, e.g. when water contents of leaf are constant, abcissic acid is released by the drying roots, under deficit irrigation (Turner, 2001). Drought is considerably affected the photosynthetic rate, which is due to weak photosynthetic system, early leaf senescence, reduced leaf development and reduced plant food production (Zafar et al., 2024).

However, the reason for improved photosynthetic rate can be that application of amendments improves the pigment composition and transpiration rate, which are helpful for photosynthesis of maize. Whereas, according to Shoukat et al. (2024), by the application of organic matter with biochar, maize physiological parameters like physiological water use efficacy enhanced. The protein, nitrogen contents and photosynthetic rate were greatly reduced under deficit irrigation that can be improved by the application of animal manure and biochar. The results of our study are also supported by El Moussaoui et al. (2024), who revealed that low water availability greatly reduces the nutrients uptake and destroys tissue concentration of the plant cells under the drought. It may be due to the disruption of uptake and absorption mechanisms with decreased transportational flow. It is finally concluded that much of water (20-30% of current use) can be saved by combined addition of animal manure and biochar into soil in 1:1 ratio @ 10 t ha^{-1}. So, combined application of animal manure and biochar can be a best tool for improved maize production under deficit irrigation.

5. CONCLUSION

Drought stress is a critical environmental factor that constrains crop production globally, exacerbated by limited organic matter and water availability in soil. Our pot experiment revealed that combined application of animal manure and biochar significantly improved the morpho-physiological and quality parameters of maize under both well-watered and deficit irrigation conditions. These findings suggest that using a combination of biochar and animal manure improved maize growth and productivity under water-deficit conditions. However, to fully realize the benefits on a larger scale, further field studies are essential to validate and refine this approach, ensuring its adaptability and effectiveness across diverse agricultural systems.

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Consent to Participate: Consent was obtained from every researcher who participated in the experiment.

Consent for Publication: The authors have given permission for this research paper to be published in the journal.

Competing Interest: The authors declare no competing interests

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