Improving soil moisture condition with biochar application for sustainable management of wheat-maize cropping system

***Sarwar N** and Abbas N
Department of Agronomy, Bahauddin Zakariya University Multan, Pakistan
*Corresponding author; naeemsarwar@bzu.edu.pk

Abstract

Climate fluctuation has created many issues for crop production like drought or deficit soil moisture condition which may reduce cereals production and enhance the food security issue for largely growing population. Cropping systems need to be re-evaluated to adapt to the climate situation or reduce demand for irrigation water. The rice-wheat cropping system established in many Asian countries has a high demand for irrigation water. In contrast, a wheat-maize cropping system is emerging as an alternative, which needs less water input. This field study was designed to see if a biochar application would further reduce the irrigation demand of the wheat-maize crops. Both crops were grown consecutively, maize following wheat crop along with full irrigation as well as with deficit irrigation (25%, 50%, 75%) with or without addition of biochar (5ton/ha). Crops were observed for dry matter distribution among various parts, yield and quality. Results revealed that a deficit irrigation approach (25% deficit + Biochar) yielded similar to full irrigation treatment. But higher water deficits (>25%) negatively impacted crop yields. It was also observed that missing irrigation or reducing irrigation up to 50% or 75% cannot be recovered with a biochar application.

Introduction

The World's population is growing fast which is increasing the food security issue. To meet the food demand, availability of fresh water is one the key factors which are shrinking due to changing climate. Rice-wheat cropping system is dominant in Asia and requires a lot of inputs (Sarwar et al., 2022) and have forced the farmers to think for alternative crops to save irrigation water. Maize-wheat cropping system provide the food to 20% population of south Asia and China (Khalofah et al., 2020). Growing maize and wheat or maize on aerobic soil (non-flooded) is an important approach for water saving.

Biochar is charrated material produced from variety of organic biomass or feedstock material through a process called pyrolysis at varying temperature under absence of oxygen (Dixon et al., 2009; Lehman et al., 2011). Biochar has high potential to increase soil porosity, water content, soil fertility, soil microbial activity, mitigates the adverse effects of various stresses and consequently increases plant growth (Mansoor et al., 2021; Sarwar et al., 2022). Biochar is a material which has high surface area and can act as the sponge for absorption of nutrients and soil moisture. It binds the soil moisture contents and makes it available for plant uptake (Haider et al., 2021). Biochar remains in the soil for years and helps maintain the soil temperature. In Pakistan, overall temperature is high which burn the soil organic matter and reduces its soil contents while the biochar can provide the better option as it remains in the soil for years.

Wheat-maize cropping system is exhaustive system which needs the proper nutrition as well as the soil moisture to ensure better productivity. To test this we conducted a field experiment using biochar under different soil moisture contents. Our overall objective was to see the role of biochar for maintaining soil moisture under sufficient or limited irrigation water.

Materials and Methods

The field experiment was carried out at Agronomic Research Farm, Department of Agronomy, Bahauddin Zakariya University, Multan during 2018-19 and 2019-20. Maize crop was sown in July and harvested in early October while the wheat crop was sown in late October and harvested in April. The response of maize hybrids (YH 5394, YH 1898 and FH 1046) and wheat cultivars (Millat-2011, Punjab-2011 and Galaxy-2013) was evaluated with full irrigation as well as with deficit irrigation (25%, 50%, 75%) with or without addition of biochar (5ton/ha). Full irrigation treatment was managed without biochar application and compared with the deficit irrigation with addition of biochar. The trial was laid out RCBD with factorial arrangement. Biochar was prepared from cotton sticks harvested from the agronomic field procedure described in pot experiments. Economical and suitable rate of biochar (5 t ha^{-1}) was selected on the basis of results of pot experiments.

For good soil tilth and seed bed preparation, soil was ploughed and cultivated three times followed by planking each time to break the clods. The soaking irrigation was provided after preparing the field and after few days when field moisture level was at field capacity, biochar at 5 t ha^{-1} was mixed with in soil. The crop was sown at a seed rate 25 kg ha^{-1} and 125 kg ha^{-1} for maize hybrid and wheat crop respectively. The plot size of each treatment unit was 6 m × 1.8 m keeping row spacing of 22.5 cm for wheat crop and 75cm for maize.

Recommended doses of N, P and K were applied (220-140-90 kg ha^{-1}) for maize crop. All the quantity of P and K while half quantity of N was applied during crop sowing and remaining N was given in 2 equal doses at 15 days after germination and 2nd at tasseling stage. For the wheat crop, recommended dose of fertilizer (120-80-60 kg ha-1) for NPK was used while the nitrogen dose was decreased as per treatment plan. All the P and K, and 1/3 of the nitrogen, were applied at the sowing time, while the rest of the N was given to the crop in two equal splits at the tillering and booting stages. Weeds were removed via manual hoeing. Irrigations were provided according to needs using canal water. We managed the deficit irrigation by missing irrigation than the normal crop requirement for both crops. Crops were harvested manually when matured and spread in representative treatment plots for sun drying. After sun drying, the biological yield was measured by weighing sun dried bundles with help of a spring balance.

Results

Results revealed that both crops enhanced their productivity under normal irrigation while we also got promising results with biochar treatments. In maize crop, all genotypes (G1, G2, G3) recorded heavier grains under normal irrigation (I1) while it was further at apar with the treatment I2 (25% deficit irrigation+ biochar) combinations: I2G1, I2G2 and I2G3. In case of grain yield, although normal irrigation with different genotypes performed superior while treatment I2 also have produced statistically similar grain yield. Almost similar trend was exhibited under harvest index in which both normal and 25% deficit irrigation along with biochar performed better. While all other treatments exceeding deficit irrigation than 25% could not give better results even with biochar application (Table-1).

In case of wheat crop, we recorded variation in wheat genotypes under different treatment application. Genotype G2 & G3, recoded heavier grain under normal irrigation which was statistically similar with I2G3 in which 25% deficit irrigation was applied with the addition of biochar. While all other combinations using different treatments recorded lighter grains. Genotype G3, also recorded higher grain yield with I2 treatment combination in which we saved 25% irrigation with supplementation of biochar. Aforementioned genotype also enhanced harvest index under normal irrigation as well as with 25% deficit irrigation & biochar. All other treatments could not perform better with or without biochar application (Table-1).

Discussion

Both crops performed better under normal irrigation level while biochar application with 25% deficit irrigation also gave similar results. It might be due to the better retaining of soil moisture as well as the nutrients in the soil under biochar application. Biochar is a pyrolyzed material having higher surface area and can absorb or bind the nutrients as well as the soil moisture ((Lehmann et al., 2020; Ruan et al., 2024).). This might be the reason that crop grown with addition of biochar and 25% deficit irrigation performed similar with the normal irrigation treatment. Under both treatments' plants uptake, the nutrient along with ambient soil moisture and could not face the stress. Due to this, both crops enhanced the plant growth and recorded the heavier grains which may enhanced the end product or grain yield. Biochar is concentrated carbon which can remain in the soil for longer time and provide the habitat for microorganisms (Lu and Zong, 2018) which are most important for mineralization and soil health.

Its also clear from the results crop was badly affected under no irrigation or under higher deficit irrigation beyond 50%. Both are the intensive crops which needs the better management for irrigation as well for the soil nutrients. Any stress may reduce the crop growth or yield. It shows that under these treatments plant could not get the proper soil moisture or nutrients and so reduced the growth or hampered other physiological mechanisms. Water is very important for the normal functioning of the plant physiological mechanisms as it's an integral component of photosynthesis on which crop yield is dependent. Similarly, the soil moisture is also needed for nutrient uptake. this is because the both crops performed better under normal irrigation while reduced the crop yield under deficit irrigation exceeding 25%. Results revealed that biochar addition managed the 25% deficit irrigation as it may absorb soil moisture and enhanced soil field capacity which supported the crop performance. biochar supplementation improves the withstand of the plants even under drought condition (Haider et al., 2021).

Conclusions

Biochar application under deficit irrigation (25%) improved crop yield and performed similar to normal irrigation. While reducing irrigation more than 25% reduced the growth and yield of both crops and resulted in very less system productivity. It was also observed that missing irrigation or reducing irrigation up to 50% or 75% can't be affordable even with biochar application

References

Sarwar, N.; Atique, R.; Omer, F.; Allah,W.; Mubshar, H.; Ahmed, S.; Shakeel, A.; Marian, B.; Samy, F.M.; Marek, Z.; et al. Integrated nitrogen management improves productivity and economic returns of wheat-maize cropping system. J. King Saud Uni. Sci. **2022**,33, 101475.

Khalofah, A.; Khan, M.I.; Arif, M.; Hussain, A.; Ullah, R.; Irfan, M.; Mahpara, S.; Shah, R.U.; Ansari, M.J.; Kintl, A.; et al. Deep placement of nitrogen fertilizer improves yield, nitrogen use efficiency and economic returns of transplanted fine rice. PLoS ONE**2021**, 16, e0247529.

Dixon, J.; Braun, H.-J.; Kosina, P.; Crouch, J.H. Wheat Facts and Futures 2009; Cimmyt: Mexico City, Mexico, 2009.

Lehmann, J.; Rillig, M.C.; Thies, J.; Masiello, C.A.; Hockaday, W.C.; Crowley, D. Biochar effects on soil biota—A review. Soil Biol.Biochem. **2011**, 43, 1812–1836

Lu, S., & Zong, Y. (2018). Pore structure and environmental serves of biochars derived from different feedstocks and pyrolysis conditions. Environmental Science and Pollution Research, 25(30), 30401–30409. https://doi.org/10.1007/s11356-018-3018-7

Ruan, R., Yuan, Y., Wang, C. *et al.* Biochar effects on drought tolerance in maize roots are linked to K^+ concentration, Ca^{2+} efflux, and apoplastic pH. *Plant Growth Regul* **103**, 307–320 (2024)

Mansoor, S., Navneet K., Sweeta M, Sheikh Z, Owais A.W, Vikas S, Leonard W, Mohammed N.A, Abdulaziz A. A, Hamed A. El, Bilal A.P, Parvaiz A. 2021. Biochar as a tool for effective management of drought and heavy metal toxicity, Chemosphere, 271: 129458,

Haider, I., Muhammad A.S. R, Rashid I., Muhammad U.A, Muhammad H.R, Shameem R., Muhammad T.K, Muhammad M.A, Muhammad W, Salman A. 2020 Potential effects of biochar application on mitigating the drought stress implications on wheat (Triticum aestivum L.) under various growth stages, Journal of Saudi Chemical Society. 24: 974-981

Table-1: Effect of deficit irrigation and biochar on crop yield and yield attributing factors in maize-wheat cropping system (average of both years)

Treat.	Maize			Wheat		
	1000-GW (g)	**GY (t/ha)**	**HI (%)**	**1000-GW (g)**	**GY (kg/ha)**	**HI (%)**
I_0G_1	177 f	1.84 g	23.26 ef	18.98 i	1431 i	22.08 g
I_1G_1	335 a	5.74ab	35.10 a	36.31 bc	4733 c	34.34 c
I_2G_1	331 a	5.67 b	34.73 a	35.87 c	4781 c	34.77 bc
I_3G_1	258 c	3.12 d	27.62 b	27.85 f	2626 e	27.72 e
I_4G_1	203 e	2.15 f	24.52cd	21.84 h	1719 gh	23.57 f
I_0G_2	176 f	1.78 gh	22.47 g	18.80 i	1424 i	22.29 g
I_1G_2	337 a	5.79 a	35.41 a	36.38 abc	4724 c	34.27 c
I_2G_2	333 a	5.72ab	34.80 a	35.98 bc	4790 c	34.87 abc
I_3G_2	267 b	3.23 c	27.43 b	28.54 e	2714 e	27.46 e
I_4G_2	217 d	2.26 e	23.91 de	21.88 h	1744 g	24.29 f
I_0G_3	175 f	1.74 h	22.65fg	19.34 i	1627 h	24.04 f
I_1G_3	335 a	5.74ab	35.08 a	37.03 a	4970 b	35.53 ab
I_2G_3	332 a	5.67 b	34.79 a	36.59 ab	5067 a	36.03 a
I_3G_3	264 bc	3.22 c	27.32 b	29.41 d	2924 d	29.06 d
I_4G_3	203 e	2.16 f	25.05 c	23.85 g	2193 f	27.16 e
LSD0.05	6.47	0.07	0.73	0.67	96	1.18

I0: No irrigation, I1: full irrigation, I2: 25% deficit irrigation + 5 t ha-1 biochar, I3: 50% deficit irrigation + 5 t ha-1 biochar, I4: 75% deficit irrigation + 5 t ha-1 biochar, **Maize** (G1: YH 5394, G2: YH 1898 and G3: FH 1046), Wheat (G1: Punjab-2011, G2: Millat- 2011, G3: Galaxy-2013)