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Biochar influences nitrogen and phosphorus use efficiency of tomato and soil nutrients under groundwater and wastewater irrigation

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Abstract

Wastewater irrigation is a common practice in developing countries, while the application of biochar in agricultural lands is gathering momentum worldwide. However, it is not known how biochar and wastewater in concert influence the uptake and concentration of nutrients in plants and soil, respectively. The influence was investigated of biochar on the growth performance of tomato plants grown in pots and the concentration of mineral N and soluble P in soil under wastewater and groundwater irrigation. Two biochars (wood-derived and manure-derived) were applied to soil as 3% and 7% amendments and tomato plants were grown. Both biochar types tended to increase the aboveground and belowground biomass and water use efficiency of plants at the higher application rate under both irrigation treatments ($p < 0.05$). The N contents in plant tissues were significantly higher for almost all treatments of biochar application rate under both irrigation treatments while under wastewater irrigation, biochar significantly reduced the P contents. The nitrogen use efficiency and phosphorus use efficiency of plants tended to increase ($p < 0.05$) at higher biochar application rates under both irrigation treatments. Amendment using biochars increased the concentration of mineral N and soluble P at both application rates under groundwater irrigation while under wastewater irrigation, only the P contents were increased in response to both biochar types at both application rates ($p < 0.05$).

Introduction

Mineral nitrogen (N) and soluble inorganic phosphorus (P) in soil are some of the most important limiting factors in crop production worldwide and farmers use inorganic and organic fertilizers to achieve high agronomic output (Ziadi et al., 2013). However, the cost of inorganic fertilizers especially mineral P is expected to become expensive because of the diminishing global reserves of rock phosphate, which is used in the production of this fertilizer (Ziadi et al., 2013).

The bioavailability of mineral N and soluble inorganic P to plants can be improved with organic amendments in soil (Gul et al., 2014, Gul and Whalen, 2016). Biochar, a pyrogenous biomass, is well known for its positive influence on soil quality and crop production,

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especially when applied with organic wastes (Gul et al., 2015; Gul and Whalen, 2016). Due to its porous and alkaline nature, biochar when applied with organic and inorganic fertilizers, improves soil properties in terms of nutrient and water holding capacity and provides microhabitat and refuge to microorganisms (Gul et al., 2015; Gul and Whalen, 2016). Therefore, its amendment in soil increases microbial abundance and activity leading to enhanced N and P cycling in soil (Gul et al., 2015; Gul and Whalen, 2016). Furthermore, as biochar-based organic amendments improve plant root growth and microbial abundance, roots and microorganisms secrete organic acids, which help in the solubilization of P from its precipitated form to a plant-available form (Vassilev et al., 2013; He et al., 2014; Mendes et al., 2014; Deb et al., 2016). Therefore, application of biochar-based organic amendments in soil tends to increase the concentration of plant-available N and P (Gul and Whalen, 2016). The influence of biochar on soil nitrogen and phosphorus cycling has been well documented (Gul and Whalen, 2016). However, the influence of biochar on soil properties and crop growth performance depends on its source of production and biochars produced from wood have many-fold less nutrients than biochars produced from manure (Gul et al., 2015). In general, biochar produced from manure has a more positive influence on soil fertility and crop growth performance than wood-derived biochar (Gul et al., 2015; Gul and Whalen, 2016).

The influence of biochar amendment in the soil on crop growth performance and soil fertility may also depend on the type of irrigation such as surface or groundwater or municipal sewage wastewater. Wastewater irrigation is a common practice especially in water scarce regions as it reduces the need for surface/groundwater irrigation, saving this resource for human consumption (Khan et al., 2013). Furthermore, the use of wastewater for irrigation purposes is considered to be a proper waste management strategy because this reduces pollution of aquatic environment and of fresh water, thus helping to reduce diseases in humans and domestic animals (Valipour and Singh, 2016; Goncalves et al., 2017). The utility of wastewater irrigation for high agronomic output with reduced reliance on inorganic fertilizers can be achieved if biochar is applied to soil.

Wastewater irrigation in arid regions of Pakistan can help promote agriculture as water is the most limiting factor for crop production, specifically in Balochistan province, which is mostly arid to semi-arid. This province is the major producer of tomatoes, accounting for 43% of the total production of this crop in Pakistan (Ministry of National Food Security and Research, 2015). In urban areas such as Quetta city, wastewater irrigation is a common practice (Hameeda et al., 2019). Knowledge of the influence of biochar on the growth performance of tomato crops and the concentration of mineral N and P in wastewater-irrigated soil can be useful to the farmers of this region regarding utilization of biochar and wastewater to enhance tomato production, which will reduce the need for inorganic fertilizer. The current research aimed to assess the influence of two biochar types—wood-derived and cow manure-derived—on tomato growth performance based on biomass production, water use efficiency (WUE), nitrogen use efficiency (NUE), phosphorus use efficiency (PUE) and the concentration of mineral N and soluble P in soil under groundwater and wastewater irrigation.

Materials and Methods

Biochars and irrigation water

The soil used in this study was a sandy loam. Soil was air-dried and passed through a 2 mm mesh sieve. Wood-derived biochar was obtained from a local timber market in Pakistan. Cow manure-derived biochar was produced in a home-made kiln. As both biochar types were produced in kilns under oxygen deficient conditions, the production temperature was 350−500°C (Spokas et al., 2011; Deal et al., 2012; Mia et al., 2015). The properties of biochars are provided in Table 1 and reported by Ghori et al. (in press) and Tahir et al. (2018). Wastewater was obtained from Spini road Quetta city, Balochistan, Pakistan. The properties of groundwater and wastewater are provided in Table 1.

Table 1 Chemical properties of groundwater, wastewater, wood-derived biochar and manure-derived biochar used in this study

Chemical property	Groundwater (ppm)	Wastewater (ppm)	Wood-derived biochar (mg/g)	Manure-derived biochar (mg/g)
pH	nd	nd	8.73	9.72
*Organic matter (%)	nd	nd	71	35
*Ash (%)	nd	nd	29	65
*Phosphorus	nd	nd	3.46	1.47
Chromium	0	0.14	0.02	0.02
Copper	0	0	7.20	0.06
Iron	0	3.58	0.63	8.01
Manganese	2.1	3.78	0.04	0.04
Nickle	0.49	0.33	3.40	0.04
Zinc	0.73	4.88	0.09	0.32
Magnesium	87.5	111.7	2.54	7.76

ppm = parts per million; nd = not determined

* = data from Hameeda et al. (2019) (used the same biochar).

Experimental design and sowing of seeds

Two biochar types (cow manure-derived and wood-derived) were amended in soil at 3% (3 g biochar in 95 g soil) and 7% (7 g biochar in 91 g soil) application rates in bottom-perforated plastic pots (10 cm diameter, 20 cm height). Soil was also amended with an air-dried mixture of cow and sheep/goat manure at a 2% (2 g manure in 98 g soil-biochar mixture) application rate as organic fertilizer. The use of inorganic fertilizer was avoided as the influence of the biochar-manure mixture on tomato growth performance was being assessed.

With three replications of each treatment, there were three factors (irrigation type, biochar type, biochar application rate) and 10 treatments consisting of: groundwater control (Control GW), sewage wastewater control (Control SW), wood-derived biochar amended at 3% and 7% application rates in soil of groundwater irrigation treatment (GWBW 3% and GWBW 7%, respectively), cow manure-derived biochar amended at 3% and 7% application rates in soil of groundwater irrigation treatment (GWBC 3% and GWBC 7%, respectively), wood-derived biochar amended at 3% and 7% application rates in soil of sewage wastewater irrigation treatment (SWBW 3% and SWBW 7%, respectively) and cow manure-derived biochar amended at 3% and 7% application rates in soil of sewage wastewater irrigation treatment (SWBC 3% and SWBC 7%, respectively). The experimental layout and abbreviations of treatments are provided in Table 2.

Table 2 Experiment layout and abbreviation of treatments

Irrigation treatment	Type of biochar	Application rate of biochar	Treatment abbreviation
Groundwater	Control	0	Control GW
	Wood-derived	3%	GWBW3%
	Biochar	7%	GWBW7%
	Manure-derived	3%	GWBC3%
	Biochar	7%	GWBC7%
Wastewater	Control	0	Control SW
	Wood-derived	3%	SWBW3%
	Biochar	7%	SWBW7%
	Manure-derived	3%	SWBC3%
	Biochar	7%	SWBC7%

A local variety of tomato (*Lycopersicon esculentum* M.) was selected for this study. Soil for all pots was provided with groundwater to 100% water-filled pore space (WFPS) before sowing of seeds to provide a soft bed for seed germination and establishment. Seeds were broadcast over the soil surface in the second week of May. The pots were placed in the laboratory at room temperature for germination. After a week, following seed germination, the pots were moved to an open area, where after 1 wk, each pot was thinned to three plants. A known amount of water was provided almost every day and the water contents were adjusted to 60% WFPS once a week as described by Gul and Whalen (2013). The sewage wastewater was provided once a week to the plants in the wastewater treatment.

Assessment of plant growth performance parameters

The water use efficiency (WUE) of tomato plants was assessed as described using Equation 1 according to Uzoma et al. (2011):

$$\text{Plant Water Use Efficiency} = (\text{Plant biomass}) / (\text{Amount of water provided}) \quad (1)$$

where the amount of water is measured in liters.

Plants were harvested after 4 mth of germination. No flower or fruit production occurred during that period which may be attributed to the late sowing of seeds, because temperature and light duration are important factors for controlling flowering in tomato plants (Calvert, 1959; Adams et al., 2001). Pots were cut away from two sides to allow careful root separation from soil. The soil moisture contents at the time of root separation were 45−50% WFPS. The soil was removed and the roots were separated from each other carefully. One plant was separated from each pot for analysis; the roots were separated from shoots and washed, and the shoots and roots were oven-dried at 50°C for 24 hr. The dry biomass of the shoots and of the roots was measured for each plant separately. The aboveground biomass of tomato plants was sent to the Soil Fertility and Plant Nutrition laboratory, Land Resources, Research Institute, National Agricultural Research Council, Islamabad, Pakistan for analysis of total nitrogen and phosphorus using the Kjeldahl method. The nitrogen use efficiency (NUE) and phosphorus use efficiency (PUE) of tomato plants were assessed using Equation 2 as described in Baligar et al. (2001):

$$\text{NUE or PUE} = (\text{Plant biomass}) / (\text{N or P contents in plant biomass}) \quad (2)$$

Assessment of mineral N and soluble P in soil

After harvest, bulked soil of each pot was air-dried, 20 g of well-mixed, air-dried soil of each sample was dissolved in 2M KCl as 1:5 w:v soil:KCl solution, followed by shaking for 1 hour on a mechanical shaker and then filtering through Whatman filter paper 41 as described in Estefan et al. (2013). The extracts were analyzed for mineral N and soluble inorganic P contents. The mineral N as nitrate (NO_3^--N) and ammonium (NH_4^+-N) was assessed following protocol described in Sims et al. (1995). The mineral N was cumulative of NO_3^--N and NH_4^+-N. Soluble inorganic P was analyzed following the protocol of D'Angelo et al. (2001). The samples were analyzed using an ultraviolet-visible spectrophotometer (Pharmaspec UV-1700; Shimadzu; Kyoto, Japan).

Statistical analysis

The data were subjected to normal distribution assessment using the D'Agostino-Pearson K^2 test, followed by analysis of variance in a three way completely randomized design. Differences between treatment means were assessed using the least significance difference test at a significance level of $p < 0.05$. All analyses were carried out using the CoStat software (CoStat 6.45).

Results

Aboveground biomass, root biomass and water use efficiency

The aboveground plant biomass was significantly different between treatments (Fig. 1). Manure-derived biochar at the higher application rate and wood-derived biochar at both application rates significantly increased the aboveground plant biomass under both irrigation treatments (Fig. 1A, 1D). The irrigation × biochar interaction was not significant (p = 0.39). The irrigation × biochar application rate interaction was not significant (p = 0.26).

Application of both biochar types at both application rates significantly increased the root biomass under groundwater irrigation (Fig. 1B), while under wastewater irrigation, manure-derived biochar at a high application rate and wood-derived biochars at both application rates significantly increased the root biomass (Fig. 1E). The irrigation × biochar interaction was not significant (p = 0.59). The irrigation × biochar application rate interaction was not significant (p = 0.15).

Biochar amendment also influenced the WUE significantly. Application of manure-derived biochar at a high application rate and wood biochar at both application rates significantly increased the root biomass under groundwater irrigation (Fig. 1C), while under wastewater irrigation, biochars at the higher application rate significantly increased the WUE (Fig. 1F). The irrigation × biochar interaction was not significant (p = 0.39). The irrigation × biochar application rate interaction was not significant (p = 0.28).

Nitrogen and phosphorus contents and in plant tissues and their use efficiency by plants

Amendment of both biochar types at both application rates significantly increased the N contents in aboveground plant tissues under both irrigation treatments (Fig. 2A, 2E). The irrigation × biochar interaction was not significant (p = 0.09). The irrigation × biochar application rate interaction was not significant (p = 0.63).

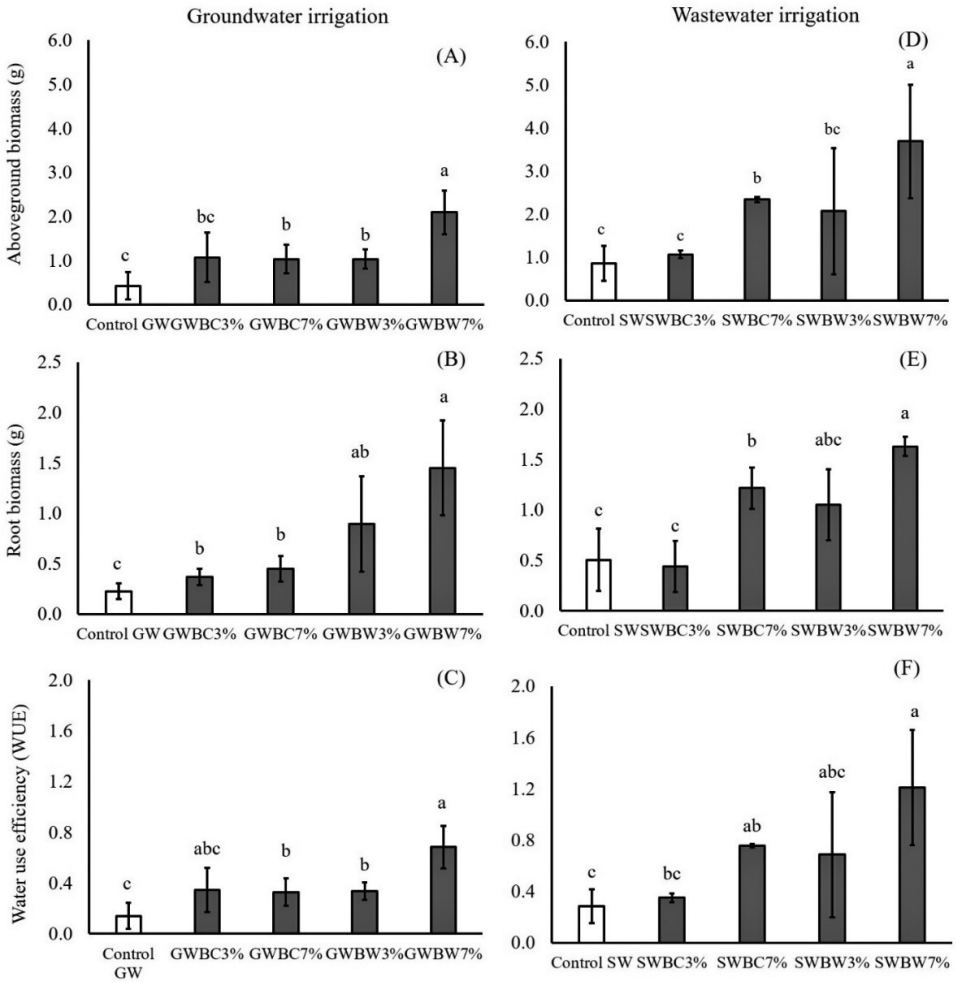


Fig. 1 Aboveground plant biomass (g), root biomass (g) and water use efficiency of tomato plants grown under groundwater (A, B, C) and sewage water irrigation (D, E, F), where bars (mean ± SD) with different letters are significantly different (p < 0.05); GW = groundwater irrigation; BC = cow manure-derived biochar; WB = wood-derived biochar; SW = sewage wastewater; 3% = biochar amendment rate at 3%; 7% = biochar amendment rate at 7%

Both biochar types at low application rates increased significantly the P contents in plant tissues under groundwater irrigation while under wastewater irrigation, the P contents in plant tissues were significantly lower in response to the amendment of both biochar types at both application rates (Fig. 2B, 2F). The irrigation × biochar interaction was significant (p = 0.000). The irrigation × biochar application rate interaction was not significant (p = 0.62).

Both biochar types at high application rate significantly increased the NUE of plants under groundwater irrigation while under wastewater irrigation only manure-derived biochar at a high application rate increased the NUE (Fig. 2C, 2G). The irrigation × biochar interaction was not significant (p = 0.85). The irrigation × biochar application rate interaction was not significant (p = 0.24).

The PUE of tomato plants was high in response to wood-derived biochar at both application rates while under wastewater irrigation, manure-derived biochar at both application rates and wood-derived biochar at a high application rate significantly increased the PUE (Fig. 2D, 2H). The irrigation × biochar interaction was not significant (p = 0.07). The irrigation × biochar application rate interaction was not significant (p = 0.12).

Concentration of mineral N and soluble inorganic P in soil

Application of biochar in soil used to grow tomato plants significantly increased the mineral N and soluble inorganic P contents of the soil (Fig. 3). The concentration of mineral N was significantly higher at all application rates of both biochar types under groundwater irrigation while under wastewater irrigation, mineral N was not significantly different among the treatments (Fig. 2). The mineral N contents were significantly higher in the soil of the control treatment of wastewater irrigation than in the soil of the control treatment of groundwater irrigation. The concentration of soluble inorganic P was significantly higher in soil amended with wood-derived biochar at both application rates and manure-derived biochar at the lower application rate under groundwater irrigation, while under wastewater irrigation both biochar types at all application rates significantly increased the concentration of soluble inorganic P (Fig. 3).

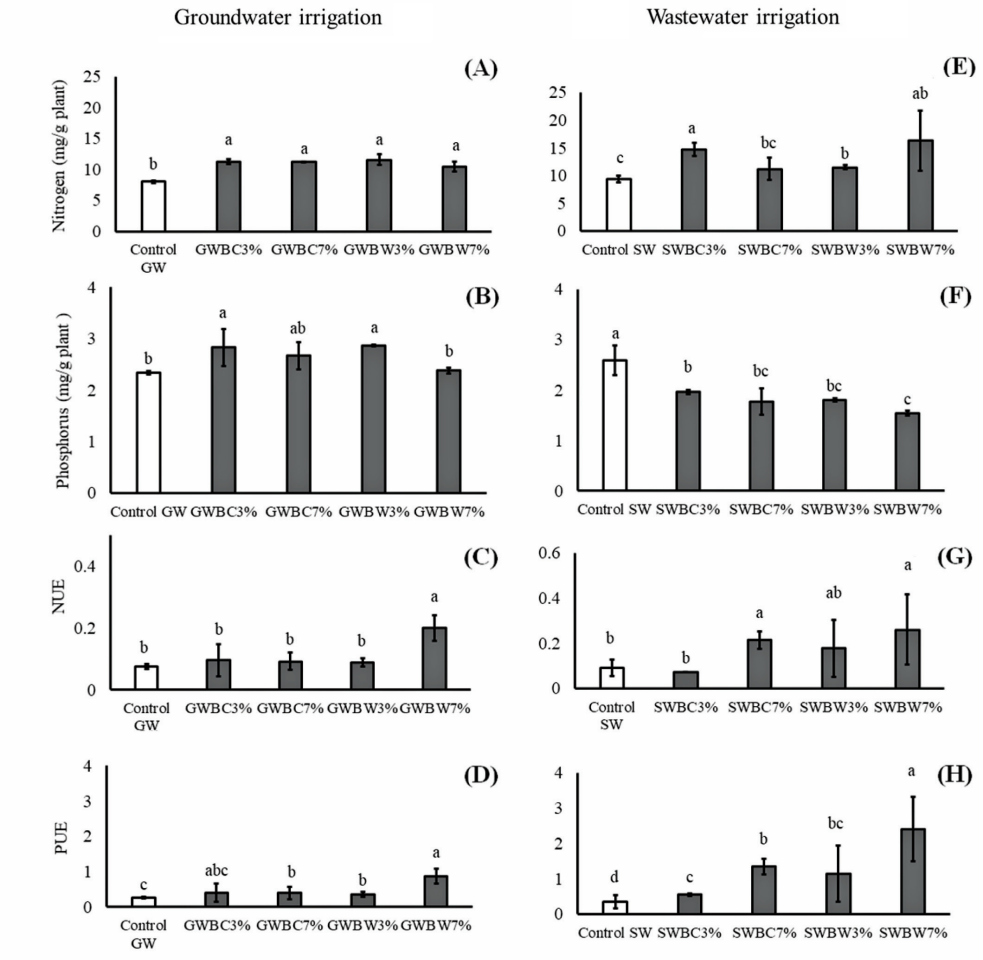


Fig. 2 Nitrogen, phosphorus, nitrogen use efficiency (NUE) and phosphorus use efficiency (PUE) of tomato plants grown under groundwater (A, B, C and D, respectively) and wastewater irrigation (E, F, G and H, respectively), where bars (mean ± SD) with different letters are significantly different (p < 0.05) and GW = groundwater irrigation; BC = cow manure-derived biochar; WB = wood-derived biochar; SW = sewage wastewater; 3% = biochar amendment rate at 3%; 7% = biochar amendment rate at 7%

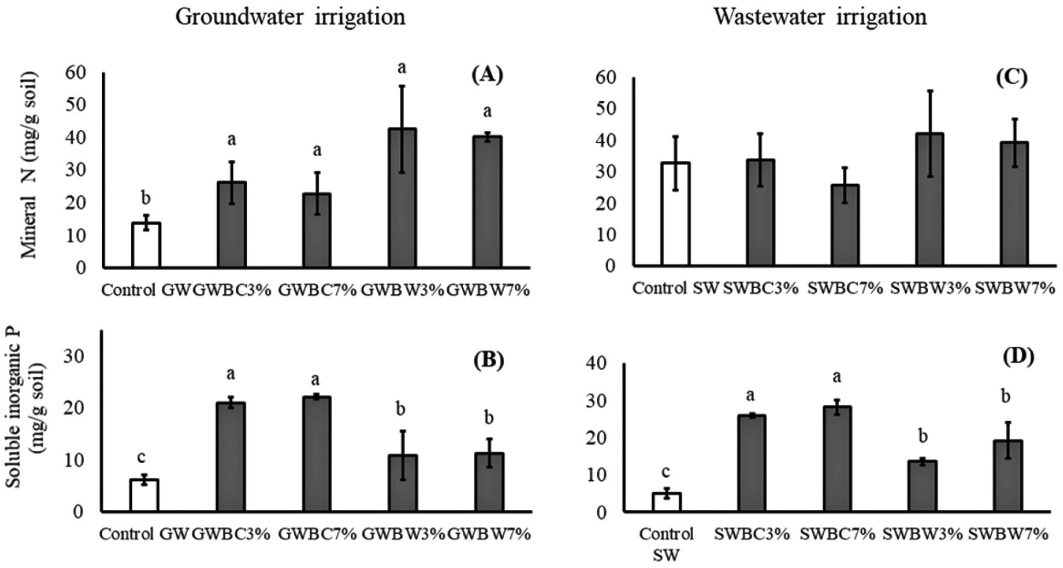


Fig. 3 Mineral nitrogen and soluble inorganic phosphorus in soil grown with tomato plants under groundwater (A, B) and wastewater (C, D) irrigation with various biochar treatments, where bars (mean ± SD) with different letters are significantly different ($p < 0.05$) and GW = groundwater irrigation; BC = cow manure-derived biochar; WB = wood-derived biochar; SW = sewage wastewater; 3% = biochar amendment rate at 3%; 7% = biochar amendment rate at 7%

Discussion

Aboveground biomass, root biomass and water use efficiency

The amendments using the biochars increased substantially the aboveground plant biomass compared to the control under groundwater (59−80% increase) and under sewage wastewater irrigation (58.5−77% increase). Likewise, root biomass was also increased under groundwater (50−84.5% increase) and under wastewater irrigation (59−69% increase) in response to biochar amendments compared to the control. These findings were in agreement with Gul and Whalen (2016) and references therein that biochar amendment increased the biomass production of crops under fresh water and with Rehman et al. (2017) under wastewater irrigation. For example, amendment of slow-pyrolyzed (production temperature 450°C) rice-straw-derived biochar at 1% in the field increased the straw yield of rice and wheat by approximately 8% and 12.7%, respectively, under wastewater effluent (Rehman et al., 2017). Plant growth may depend on the biochar concentration as demonstrated by Gul and Whalen (2016) and Hussain et al. (2017) as was evident from the current study where increasing the amendment rate of biochars increased the biomass production of the tomatoes; furthermore, the trend was similar under both irrigation types and for both wood-derived and cow manure-derived biochars. Recent findings by Haider et al. (2018) also showed a similar trend in the growth response under field conditions of turnip plants to two types of biochars (wood-derived and cow manure-derived) under both groundwater and municipal wastewater irrigation. These findings combined indicate that the application of biochars in soil does not influence plant growth performance differentially regarding the source of irrigation (for example groundwater or wastewater); however, as was evident from the current findings and the findings of Haider et al. (2018), the growth of plants was better under wastewater irrigation in response to biochar amendments. A possible explanation for this phenomenon was that wastewater has a higher concentration of nutrients and the application of biochar further enhances their bioavailability by preventing leaching.

The increase in root biomass in response to biochar amendment may positively increase the concentration of mineral N and soluble P because roots secrete organic acids and also provide food for microorganisms in the rhizosphere, which help in the mineralization of organic nitrogen and the solubilization of phosphorus from their precipitated form to a bioavailable form (Gul and Whalen, 2016). The microorganisms in the rhizosphere also secrete organic acids, which help solubilize phosphorus in soil (Gul and Whalen, 2016). The high nutrient retention capacity of biochar can capture nutrient and then act as a slow-release fertilizer (Kammann et al., 2015). Thus, high root biomass production in response to biochar amendment helps to increase the concentration of mineral N and soluble P in soil. High root biomass production in response to biochar amendment may also have implications for soil carbon sequestration as a function of the biochar directly (as biochar has very high turnover rate) and indirectly by increasing root biomass, as the roots also have higher turnover rates than leaves and shoots (Gul et al., 2012).

The WUE is the ratio of plant biomass production to water supplied to plants (Liu et al., 2016). The present study revealed an increased WUE of tomato plants under groundwater irrigation (57−79% increase) and under wastewater irrigation (62.4−76.6% increase) in response to biochar amendments, especially at the higher application rate under both irrigation types. These results were consistent with previous findings that application of biochar improves the WUE of plants (Liu et al., 2016; Zainul et al., 2017). Biochar

retains the water in its pores; thus, the quantity of available water in the soil increases, as was proven by Hardie et al. (2014) in a two-year study.

Nitrogen and phosphorus contents and their use efficiencies by tomato plants

Amendment of biochars also influenced the uptake of N and P from the soil. The N contents were significantly higher (23−30.5%) in aboveground plant tissues under groundwater irrigation in response to both biochar types at both application rates, while under wastewater irrigation, wood-derived biochar at the higher application rate showed significantly higher (63%) N contents plant tissues compared to the control treatment. These results were consistent with Deenik et al. (2011) who reported that amendment of biochar increased the N uptake and yield of plants. The NUE was also greater for plants in almost all biochar treatments (except for cow manure-derived biochar at the 7% amendment rate) under groundwater irrigation, while for wastewater irrigation increased NUE was observed for wood-derived biochar at the 7% amendment rate. These findings were in agreement with Gul and Whalen (2016) who reported that biochar positively influenced the NUE of plants.

Amendment of biochar also influenced the concentration of P in aboveground plant tissues but the trend was different to that for N. Under groundwater irrigation, biochar application increased the P contents in plant tissues (12.4−18.2%) while under wastewater irrigation, application of both biochar types at both application rates reduced the P concentration by 24.5–40.7%. However, biochar amendment positively influenced the PUE of plants under both irrigation treatments. The PUE of plants was 28.3−70.8% greater in response to wood-derived biochar at both application rates under groundwater irrigation, while under wastewater irrigation, the PUE was greater (3785%) in plants in response to almost all biochar treatments except for wood-derived biochar at the lower application rate. These findings were in agreement with previous reports that biochar amendment improved the P uptake, crop yield and PUE of plants in rain-fed or groundwater irrigation conditions (Rajkovich et al., 2012; Gul and Whalen, 2016). A greater PUE of crops is required to reduce the need for inorganic P to achieve enhanced crop yields. Therefore, the current study has implications for better yields of tomato crops by using biochar to improve the NUE and PUE of the plants. In particular, this study gives an insight into the positive influence of biochar amendment on the growth performance of tomato in arid regions under wastewater irrigation.

Concentration of mineral N and soluble inorganic P in soil

Amendment of biochar improved the concentration of mineral N and soluble inorganic P in the soil. Under groundwater irrigation, the mineral N contents were 39.5−68% greater in the biochar-amended soils and all biochar treatments showed improved soil N contents, while under wastewater irrigation, there was no difference between the biochar treatments in this regard. However, the mineral N contents were significantly higher in the soil of the wastewater control than in the soil of the groundwater control. Likewise, the soluble P contents were 43.5−72% higher in the biochar-amended soils than the control under groundwater irrigation while under wastewater irrigation, the biochar amendment increased the soil soluble inorganic P contents by 74.4−83% compared to the control. Increased P contents was observed for all biochar treatments under both irrigation treatments except for the wood-derived biochar applied at 3% amendment under wastewater irrigation. These results were consistent with previous findings that biochar amendment increased the N and P contents of soil (Chintala et al., 2014; Kammann et al., 2015).

Biochar is a porous material and can capture nutrient in the soil (Chintala et al., 2014; Kammann et al., 2015; Gul and Whalen, 2016). Moreover, it prevents nutrient leaching; therefore, amendment of this porous material causes enhanced N and P concentration in the soil (Zheng et al., 2013; Gul et al., 2015; Gul and Whalen, 2016). Furthermore, biochar's influence on the concentration of N and P in soil is mediated by its influence on root growth as described above. In general, soil is not deficient in P contents but the P contents in soil are prone to be precipitated with Al and Fe under acid conditions and with Ca and Mg under alkaline soil conditions, which makes the P less available for plants (Gul and Whalen, 2016). Furthermore, as inorganic P fertilizer is produced from rock phosphate, the price for this fertilizer is prone to be high because rock phosphate supply is diminishing (Ziadi et al., 2013). Management practices that increase the solubilization of P in the soil to produce a better crop yield can reduce the need for inorganic fertilizer. In the current study, biochar application positively increased root growth and that may be one of the possible reasons for enhanced P concentration in the soil as discussed above. To the authors' knowledge, this study was the first that demonstrated the influence of biochars on the NUE and PUE of tomato plants as well as the concentration of mineral N and soluble inorganic P of soil under wastewater irrigation. The findings of present study provide an insight to the farmers of Balochistan (the major producers of tomatoes in Pakistan and where most of the region is arid) about the positive influence of biochar on reducing the requirements of tomato plants for supplemental mineral N and soluble P via enhancing their NUE and PUE as well as via increasing the concentration of soluble inorganic P under wastewater and groundwater irrigation.

The current findings revealed that the amendment of both biochar types (wood-derived and cow manure-derived) influenced positively the above- and below-ground plant biomass, WUE, NUE and PUE of plants and the concentration of mineral N and soluble P in soil under wastewater and groundwater irrigation. Cow manure is one of the major biowastes in Balochistan, where this source is used for fuel purposes and as fertilizer (Hameeda et al., 2019). Most of this biowaste gets decomposed in urban areas without timely utilization due to its limited requirement, causing air pollution and adding greenhouse gases such as methane and nitrous oxide in air (Cao et al., 2019)). The use of cow manure as biochar can be a viable means for management of this waste. On the other hand, the major source of wood in Balochistan is pruned twigs from fruit trees, especially apple, peach, apricot, plum and almond and the wood from cutting of fruit trees

to replace them with young trees (Hameeda et al., 2019). Therefore, since this province is the producer of cow manure and wood, these two sources can be affordable for farmers to use them for agronomic purposes. The current study used these biochar types with a mixture of cow and sheep/goat manure (as the major source of manure in this province). The use of manure with biochar in this province, where the climate is mostly arid and semi-arid, has great potential to enhance crop production, reduce farmers' reliance on inorganic fertilizers and promote the proper management of manure as biowaste. Furthermore, this study can provide an insight for the farmers on how to use biochar and manure as organic fertilizer for better crop growth performance, especially in arid regions were wastewater irrigation is more common and groundwater is less readily accessible for irrigation.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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