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(Original Article)

Effects of Pyrolysis Temperatures of Tomato Stems Biochar on Soil Properties and Nitrogen Use Efficiency of Wheat Plant Grown in Sandy Soil

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Abstract

A pot experiment was conducted to investigate the potential of using tomato stems biochar (TSB) prepared at three pyrolysis temperatures (250°C, 400°C, and 600°C) as an agricultural enhancer in sandy soil to improve quality indicators, nitrogen use efficiency (NUE), and wheat growth. This experiment included the following treatments; control (no biochar added), 1% TSB250, 2.5% TSB250, 5% TSB250, 1% TSB400, 2.5% TSB400, 5% TSB400, 1% TSB600, 2.5% TSB600, and 5% TSB6000, where every type of biochar was applied at different doses (1, 2.5, and 5% w/w). The experiment was designed in a completely randomized design with three replications. Compared to the unamended soil, applying TSB250 decreased significantly soil pH from 8.25 for Control to 8.17, 7.73, and 7.62 for levels 1%, 2.5%, and 5% respectively, while the applications of TSB400, and TSB600 significantly increased soil pH. Applying TSB caused increased soil available nitrogen by 28%, 9.60%, 27.40%, 45%, and 8.70% for the TSB600 at 1, 2.5%, and TSB400 at all levels, respectively. Available nitrogen in sandy soil decreased significantly with TSB250 addition at doses of 2.5%, and 5%. Fresh and dry biomass of wheat increased significantly with the application of tomato stems biochar. Adding TSB400 and TSB600 at all doses as well as 1% TSB250 into sandy soil led to significant increases in NUE of wheat. The effectiveness of tomato stems biochar treatments on NUE increased in the order of TSB400 > TSB600 > TSB250. Based on these results, we recommend applying TSB400 at 2.5% to sandy soils.

Keywords: *Biochar; Nitrogen; Pyrolysis temperatures; Soil organic matter; Sandy soil*

Introduction

Nitrogen is often the most limiting nutrient for productivity in agricultural systems, impacting economic sustainability. Consequently, synthetic nitrogen fertilizers are applied to approximately 135 million hectares of agricultural land. Nitrogen fertilizer consumption for cereal production has surged, reaching about

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746 Tg (equivalent to 30.3 kg ha^{-1}) globally (Ladha *et al*., 2016). While the extensive use of nitrogen fertilizer has contributed significantly to meeting food demands, it has also resulted in nitrogen loss from farmland soils through runoff, leaching, and ammonia volatilization (Jia *et al*., 2014; Naz *et al*., 2019). Nitrogen use efficiency (NUE), which is the ratio of nitrogen output in crops to nitrogen input from fertilizers, typically remains below 40% for most crops (Raun *et al*., 2002; Zheng *et al*., 2013). This not only leads to low NUE and higher production costs but also poses environmental risks such as groundwater contamination (Wang *et al*., 2019), surface water pollution causing eutrophication (Ayele and Atlabachew, 2021), gaseous emissions contributing to acid rain (Penuelas *et al*., 2020), and N loss through gaseous emissions (N_2O and NH_3), exacerbating global warming (Kim *et al*., 2012; Singh *et al*., 2013). Ammonia volatilization alone results in an annual N loss of 32 Tg worldwide (Beusen *et al*., 2008).

Hence, finding effective ways to reduce nitrogen loss is imperative. Biochar has emerged as a promising material for mitigating nitrogen leaching and enhancing nutrient use efficiency in soils (Liu *et al*., 2019). Biochar, produced through the pyrolysis of organic materials at relatively low temperatures between 250 and 700 °C in the absence of air or with limited oxygen, has been shown to increase ammonium and nitrate retention and decrease nitrogen leaching (Lehmann and Joseph, 2015; Yao *et al*., 2012) and N_2O emissions (Wu *et al*., 2013) when incorporated into sandy soils. It improves the nitrogen use efficiency of plants grown in sandy soil (van Zwieten *et al*., 2010). Furthermore, biochar enhances the nutrient retention capacity and cation exchange capacity (CEC) of soils (Case *et al*., 2012) and improves soil physical, chemical, and biological properties, thereby enhancing soil health and plant growth (Lehmann, 2007; Knowles *et al*., 2011). The nutrients sorbed on biochar gradually become available to plants and microorganisms over time, leading to increased plant growth and yields in various studies (Atkinson *et al*., 2010; Major *et al*., 2010). A meta-analysis by Jeffery *et al*. (2011) found a significant 10% increase in crop productivity in biochar-amended soils compared to control soils, based on data from over 60 studies. Similarly, Baronti *et al*. (2010) and Vaccari *et al*. (2011) reported positive effects of biochar addition, up to 30%, on wheat. However, several factors can influence the role of biochar in improving soil quality, including feedstock source, manufacturing process, pyrolysis temperature, and application rate of biochar (Wiedner *et al*., 2013; Yu *et al*., 2018). Among these factors, pyrolysis temperature is a major determinant of biochar's physical and chemical properties, which in turn affect its impact on soil functionality (Zhang *et al*., 2015). The current work aimed to study the effect of different addition rates of biochar produced from tomato stems (as agricultural wastes) at different pyrolysis temperatures (250, 400, and 600 °C) on nitrogen use efficiencies, wheat growth as well as some properties of the sandy soil.

Materials and Methods

Biochar production

Tomato stems were collected from tomato fields located in Qena Governorate after the end of the harvest season and it was transported to the place designated for making biochar, after that, the stems were into particles smaller than 5 cm, and dried at 70˚C, these pieces were placed in a steel container (60 L) in an amount of about 8–10 kg, then put in a muffle furnace and subjecting them to slow pyrolysis under oxygen-limited conditions in a furnace. Three distinct pyrolysis temperatures were employed: 250 °C for 10 hours, 400 °C, and 600 °C for 4 hours. The resulting biochar samples—termed tomato stems biochar at 250 °C (TSB250), tomato stems biochar at 400 °C (TSB400), and tomato stems biochar at 600 °C (TSB600) were finely ground and sifted through a 2-mm sieve for subsequent chemical analysis.

Biochar analysis

Biochar properties were assessed through various measurements. The pH of biochar was determined in a suspension (1:20 ratio) using a pH meter, while electrical conductivity was gauged in biochar extract (1:20 ratio) using an EC meter, following the methodology outlined by (Cheng and Lehmann, 2009). Organic matter content in the biochar was quantified using the Walkley-Black method (Jackson, 1973). The contents of nitrogen, phosphorus, and potassium were analyzed by subjecting tomato stem biochar to digestion with concentrated H_2SO_4, H_2O_2, and salicylic acid (Jackson, 1973). Nitrogen content was ascertained using the Kjeldahl method (Page *et al.*, 1982). Some chemical properties of tomato stems biochar (TSB) are listed in Table 1.

Pot experiment

During the winter season of 2020/2021, a pot experiment was conducted in the screen house of South Valley University's agricultural experimental farm's Department of Soils and Water, Qena, Egypt, to study the effect of different addition rates of biochar produced from tomato stems (as agricultural wastes) at different pyrolysis temperatures (250, 400, and 600 °C) on nitrogen use efficiencies, wheat growth as well as some properties of the sandy soil. The soil used in the experiment was obtained from the top layer (0–20 cm) of the experimental farm at the Faculty of Agriculture, South Valley University, Qena, Egypt. The soil's chemical and physical characteristics can be found in Table 2. Using plastic pots of 40 cm in height and 30 cm diameter with a drainage aperture in the bottom, the pot experiment was prepared in a completely randomized design (CRD), with three replications, prepared soils were uniformly placed in plastic pots, with each pot containing 5 kg of soil. Different levels of biochar (0 as control, 1, 2.5, and 5%) were added to the soil, and the soil sample in each pot was thoroughly mixed with the investigated biochar and then 12 seeds of wheat (Giza 168) were planted in each pot. using tap water at field capacity, all pots were directly irrigated after applying all treatments. At two doses (after 15 and 30 days from planting), nitrogen was introduced to the pots at a rate of 1.2 g of ammonium nitrate (33.5% N) per pot. After 70 days from planting, the plants were harvested completely from each pot, and then the wet weight and plant height were recorded, after that, the harvested plants underwent washing with distilled water and were then dried in an oven at 70°C to determine the total dry weight per pot. Following the plant harvest, soil samples were collected from each pot. These soil samples were air-dried, crushed, passed through a 2 mm sieve, and subjected to analysis to determine their physical and chemical properties.

Table 1. Some selected properties of Tomato stems biochar

Property	Tomato stems biochar at 250°C	Tomato stems biochar at 400°C	Tomato stems biochar at 600°C
pH	6.58	8.38	9.23
EC (dS m^{-1})	6.91	8.05	8.26
C (%)	50.30	47.10	39.2
Total N (g kg^{-1})	5.4	0.38	0.29
OM (g kg^{-1})	85.46	79.40	66.64
DOC (mg kg^{-1})	8450	4200	3500
C/N	9.31	123.94	135.17
CEC (cmol kg^{-1})	19.8	38.5	10.6

OM: organic matter; EC: electrical conductivity, DOC: dissolved organic carbon, CEC: cation exchange capacity

Table 2. Physical and chemical properties of the soil used in this experiment

Sand	Silt	Clay	Texture	pH (1:2.5)	EC (1:5) (dS m^{-1})	Organic matter (g kg^{-1})	CEC (cmol kg^{-1})
89	6	5	Sandy	8.28	0.50	4.60	3.50

Soil analysis

The pH was determined in 1: 2.5 of a soil–distilled water (w/v) suspension by a glass electrode (Jackson, 1973), Electrical conductivity (EC) was measured in soil extract (1:5) using an electrical conductivity meter (Jackson, 1973). The available nitrogen in the soil after the end of this experiment was extracted by 2 M potassium chloride (Burt, 2004), and available nitrogen (NH_4^+ and NO_3^-) content was determined by the Kjeldahl method (Page *et al*., 1982). The soil samples were digested with a mixture of H_2SO_4, H_2O_2, and salicylic acid, as described by (Parkinson and Allen, 1975), and total N were analyzed according to the Kjeldahl method (Page *et al*., 1982).

Plant analysis

The chlorophyll content of the leaves was determined using a SPAD 502 m device from Minolta Corporation, Japan. The length of the wheat plant's stem and root was gauged using a measuring tape. The weight of the plant's fresh biomass was measured upon harvesting, and the dry biomass was calculated by drying in an oven at 70°C for 48 hours. The plant samples underwent digestion using a combination of sulfuric acid (H_2SO_4) and perchloric acid ($HC1O_4$). The total nitrogen content was determined using the Kjeldahl method as described by (Jackson,1973). N uptake (mg pot^{-1}) was calculated as follows: (Maniruzzaman *et al*., 2017)

$$\text{N uptake (mg pot}^{-1}\text{)}=\frac{\text{N concentration (mg kg}^{-1}\text{) in plant part(dry matter)}\times\text{dry biomass g pot}^{-1}}{1000}$$

N use efficiency (NUE): NUE was calculated using the following (Daradjat *et al.*, 1991)

$$\text{NUE \%}=\frac{\text{N uptake Green biomass (g pot}^{-1}\text{)}}{\text{N applied (g pot}^{-1}\text{)}}\times 100$$

Statistical analyses

The statistical analysis of the data was performed by using STATISTIX 9.0 (C) Analytical Software (1985-2008). The differences among the treatments were analyzed with the Tukey multiple range test, and differences were considered significant when $P \leq 0.05$.

Results

Tomato stems biochar effects on soil pH and available nitrogen

The soil pH values after 70 days of cultivation are shown in Figure 1. Soil pH value showed an increasing trend with the increase of pyrolysis temperature and the level of addition of biochar with applications of TSB400 and TSB600 compared to the control pH (8.25) where it increased significantly ($p \leq 0.05$). The pH values were 8.26, 8.35, 8.43, 8.51, 8.63 and 8.86 for 1% TSB400, 2.5% TSB400, 5% TSB400, 1% TSB600, 2.5% TSB600 and 5% TSB600, respectively. On the contrary in the TSB250 treatments, the soil pH values decreased from 8.25 in the control treatment to 8.17, 7.73, and 7.62 for 1% TSB250, 2.5% TSB250, and 5% TSB250, respectively. Additionally, the 5% TSB600 biochar treatment showed the largest pH increase, which was 8.86, while, the 5% TSB250 biochar treatment showed the largest pH decrease, which was 8.86.

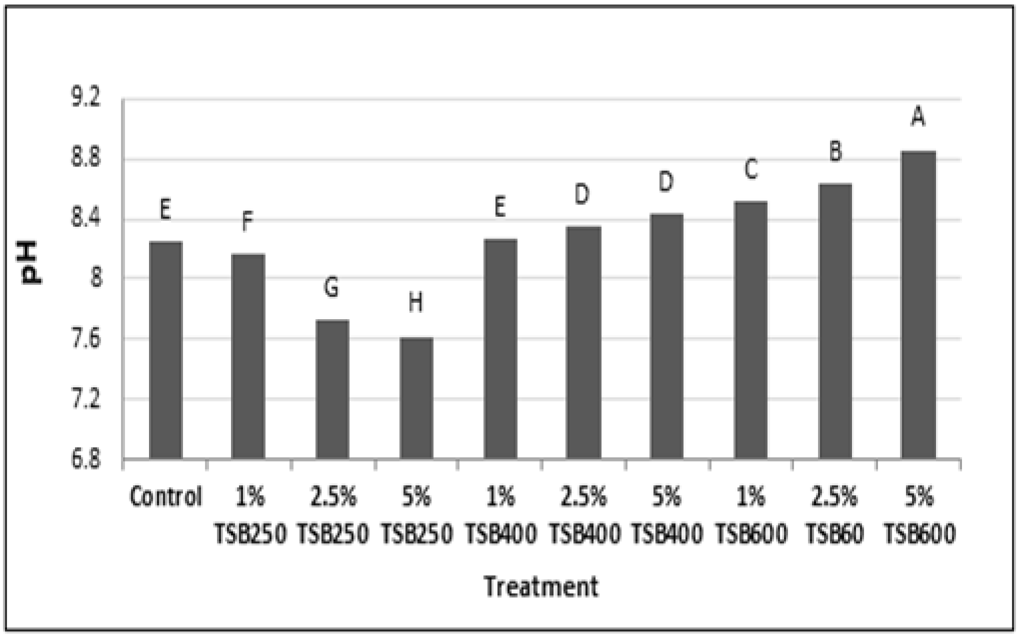

Fig. 1. Effects of tomato stems biochar adding treatments (1% TSB250, 2.5% TSB250, 5% TSB250, 1% TSB400, 2.5% TSB400, 5% TSB400, 1% TSB600, 2.5% TSB600, and 5% TSB600) on soil pH.

The concentration of available nitrogen increased from 11.40 mg kg^{-1} in the control treatment to 14.53, 16.53, 12.40, 14.60, and 12.50 mg kg^{-1} for the 1% TSB400, 2.5% TSB400, 5% TSB400, 1% TSB600, and 2.5% TSB600 treatments, respectively. Conversely, the concentration of available nitrogen decreased from 11.40 mg kg-1 in the control treatment to 11.36, 10.26, 9.46, and 10.36 mg kg^{-1} for the 1% TSB250, 2.5% TSB250, 5% TSB250, and 5% TSB600 treatments, respectively (Table 3).

Table 3. Effects of tomato stems biochar on available nitrogen, nitrogen uptake, and nitrogen use efficiency (NUE)

Treatments		Available nitrogen (mg kg^{-1})	N Uptake (mg pot^{-1})	NUE (%)
Control		11.40^{D}	132.80^{H}	33.33^{G}
TSB 250	**1%**	11.36^{D}	143.40^{G}	35.70^{F}
	2.5%	10.26^{E}	131.73^{I}	32.76^{H}
	5%	9.46^{F}	124.63^{J}	31.20^{I}
TSB 400	**1%**	14.53^{B}	171.57^{B}	42.80^{B}
	2.5%	16.53^{A}	191.30^{A}	47.63^{A}
	5%	12.40^{C}	162.70^{C}	40.70^{C}
TSB 600	**1%**	14.60^{B}	155.80^{E}	38.90^{D}
	2.5%	12.50^{C}	160.20^{D}	40.30^{C}
	5%	10.36^{E}	151.53^{F}	37.66^{E}

TSB250: tomato stems biochar pyrolyzed at 250 °C; TSB400, tomato stems biochar pyrolyzed at 400 °C; TSB600, tomato stems biochar pyrolyzed at 600 °C. Different superscript lowercase letters in each column showed significant differences between treatments according to Tukey's Honestly Significant Difference test at $P \leq 0.05$.

Effects of tomato stems biochar application on nitrogen uptake and nitrogen use efficiency

The results in Table 3 show that, except for two treatments nitrogen uptake decreased from 132.80 mg pot^{-1} for the control treatment to 131.73 and 124.63 mg pot-1 for 2.5% TSB250 and 5% TSB250, respectively. On the other hand, in the rest treatments, the addition of tomato stems biochar at all pyrolysis temperatures and levels led to significant increases ($p \leq 0.05$) of nitrogen uptake by wheat plants, from 132.80 mg pot^{-1} for the control treatment to 143.40, 171.57, 191.30, 162.70, 155.80, 160.20 and 151.53 mg pot^{-1} for 1% TSB250, 1% TSB400, 2.5% TSB400, 5% TSB400, 1% TSB600, 2.5% TSB600, and 5% TSB600, respectively. The lowest value of uptake of nitrogen was observed by applying 5% TSB250 for 124.63 mg pot pot^{-1}. The highest value of nitrogen uptake was observed by applying TSB400 at level 2.5% recorded at 191.30 mg pot^{-1}. The effect of biochar on nitrogen use efficiencies was similar to nitrogen uptake, where Biochar applications 1% TSB250, 1% TSB400, 2.5% TSB400, 5% TSB400, 1% TSB600, 2.5% TSB600, and 5% TSB600, respectively, led to a significant increase ($p \leq 0.05$) in nitrogen use efficiencies from 33.33 % for the control treatment to 35.70, 42.80, 47.63, 40.70, 38.90, 40.30 and 37.66 %, respectively while, nitrogen use efficiencies decreased from 33.33 % for the control treatment to 32.76 and 31.20 % for 2.5% TSB250 and 5% TSB250, respectively (Table 3). Generally, the results show that, in most cases, the highest values of nitrogen uptake and nitrogen use efficiencies were recorded under 400 °C biochar (TSB400) treatments compared to other treatments.

Effects of tomato stems biochar application on green and dry Biomass

Figure 2. shows that biochar applications at all pyrolysis temperatures and levels led to an increase significantly ($p \leq 0.05$) in green biomass of wheat plant by 7.7, 40.1, 59.7, 38.2, 74.5, 29.7, 27.4, 13.1, and 4.7 % for 1% TSB 250, 2,5% TSB 250, 5% TSB 250,1% TSB 400, 2.5% TSB 400, 5% TSB 400, 1% TSB 600, 2.5% TSB600, and 5% TSB 600, respectively compared to the control treatment. Moreover, TSB 400 treatment at level 2.5% resulted in the highest green biomass, the 2.5% concentration of biochar consistently outperformed other concentrations across all biochar types. Also, the results explained, that dry biomass followed a similar trend to green biomass, with biochar treatments leading to significant improvements by 6.3, 42.1, 53.2, 31.9, 74.1, 25.6, 23.7, 12.7 and 5.4 % for 1% TSB 250, 2,5% TSB 250, 5% TSB 250,1% TSB 400, 2.5% TSB 400, 5% TSB 400, 1% TSB 600, 2.5% TSB 600, and 5% TSB 600, respectively compared over the control treatment (Figure 3). Additionally, TSB 400 treatment at level 2.5% recorded the highest dry biomass, followed by TSB 250 at level 5%. The 2.5% concentration of biochar demonstrated its efficacy in enhancing biomass production.

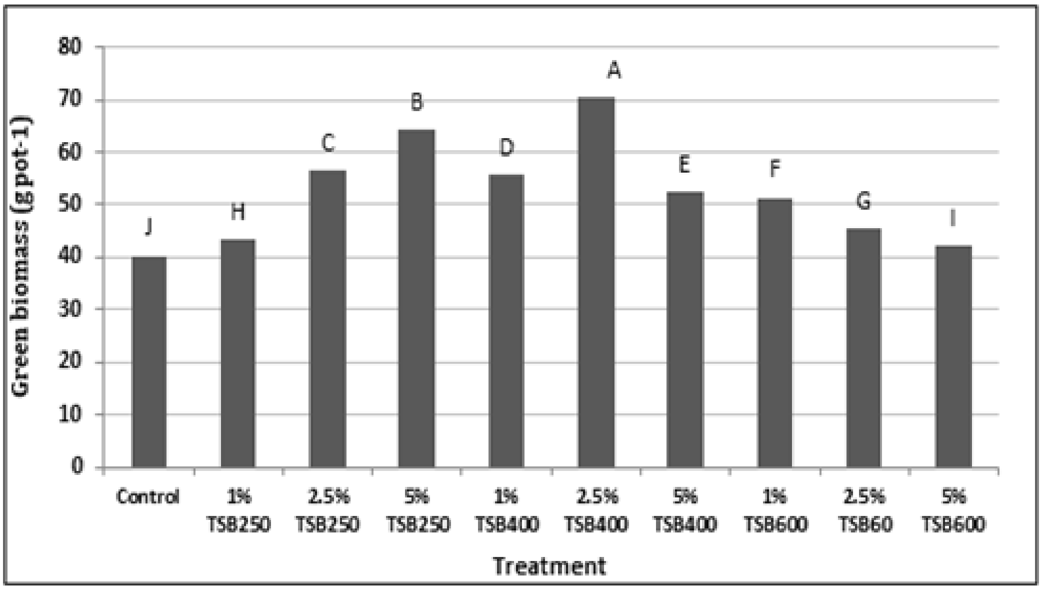

Fig. 2. Green biomass of wheat plant with adding biochar treatments (1% TSB250, 2.5% TSB250, 5% TSB250, 1% TSB400, 2.5% TSB400, 5% TSB400, 1% TSB600, 2.5% TSB600 and 5% TSB600) to sandy soil

Effects of tomato stems biochar application on chlorophyll Content

Figure 4 showed that the application of tomato stems biochar led to an increase significantly ($p \leq 0.05$) in the Chlorophyll content of wheat plant by 11.5, 34.9,43.5, 29.1, 49.6, 26.2, 17.2, 8.6 and 5.6 % for 1% TSB 250, 2,5% TSB 250, 5% TSB 250,1% TSB 400, 2.5% TSB 400, 5% TSB 400, 1% TSB 600, 2.5% TSB 600, and

5% TSB 600, respectively compared with control treatment. Moreover, the application of TBC400 at level 2.5% recorded the highest chlorophyll content, this suggests that biochar, especially at the 2.5% concentration, positively affected the plant's ability to photosynthesize and produce chlorophyll.

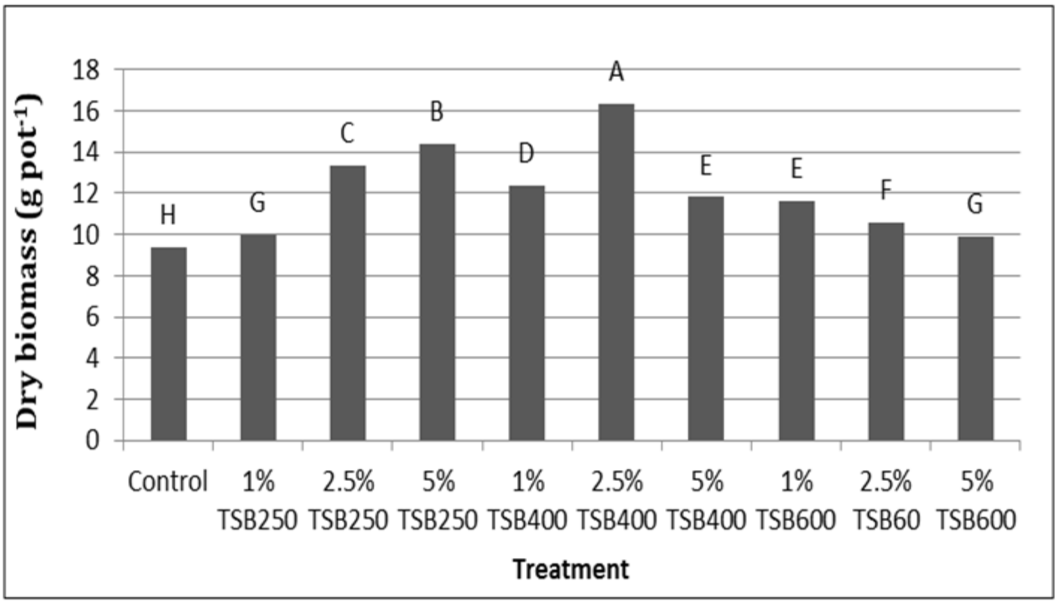

Fig. 3. Dry biomass of wheat plant with adding biochar treatments (1% TSB250, 2.5% TSB250, 5% TSB250, 1% TSB400, 2.5% TSB400, 5% TSB400, 1% TSB600, 2.5% TSB600 and 5% TSB600) to sandy soil.

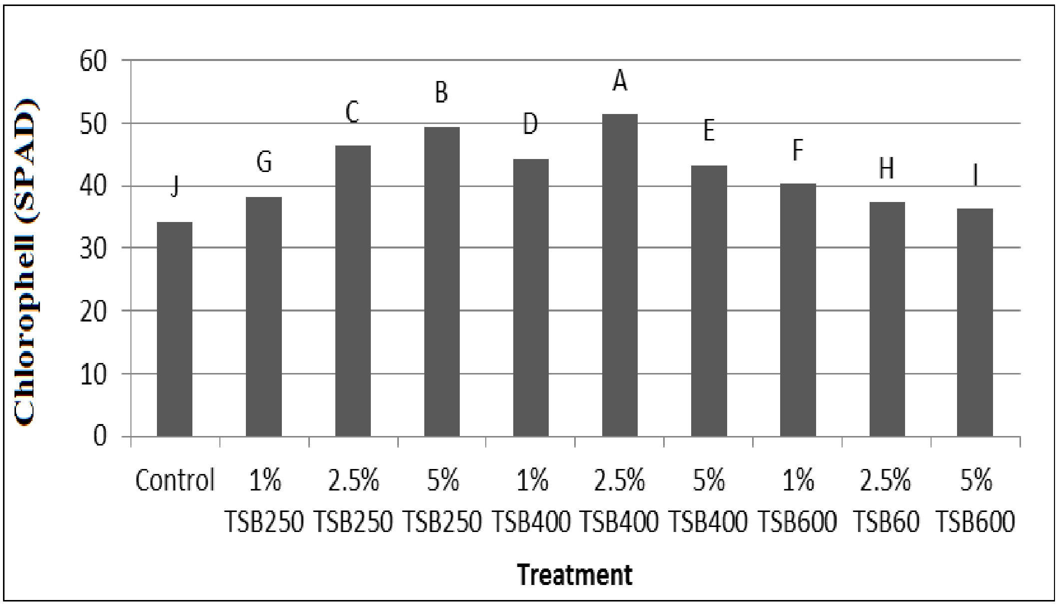

Fig. 4. Chlorophyll content in wheat plant with adding biochar treatments (1% TSB250, 2.5% TSB250, 5% TSB250, 1% TSB400, 2.5% TSB400, 5% TSB400, 1% TSB600, 2.5% TSB600 and 5% TSB600) to sandy soil.

Discussion

Impact of tomato stems biochar application on soil properties

The results indicate that higher pyrolysis temperatures, specifically TSB400 and TSB600, led to a significant increase in soil pH. This increase was attributed to the alkaline nature of biochar containing K, Ca, and Mg (Gaskin *et al.*, 2010; Joseph *et al.*, 2010), which exchanges H+ ions with soil colloids, resulting in elevated soil pH (Randolph *et al.*, 2017). This is consistent with previous research indicating that biochar applications can elevate soil pH (Berek, 2014; Lehmann and Rondon, 2006), for instance, El-Naggar *et al.* (2018) observed a sharp increase in pH in sandy soil after the application of biochar. Also, Chathurika *et al.* (2016) found that amended soils with 1% and 2% (w/w) recorded a significant increase in soil pH after 70 days from planting compared to non-biochar-amended soils. Conversely, in the TSB250 treatments, the soil pH values decreased. This decrease can be explained by the presence of acidic functional groups on the surface of biochar produced at lower temperatures, as well as the production of organic acids and phenolic substances during low-temperature pyrolysis (Amin, 2020; Amin, 2022; Zhang and Wang, 2016). These factors collectively contribute to a decrease in soil pH. So, the study highlights the importance of considering both pyrolysis temperature and biochar dosage when assessing its impact on soil pH.

The application of biochar has a significant influence on available nitrogen content in sandy soil, with varying effects observed across different treatments. Notably, the application of TSB600 at levels 1% and 2.5%, as well as TSB400 at all levels, led to a substantial increase in available nitrogen content compared to the control treatment ($p \leq 0.05$) (Table 3). Our findings resonate with (Mukherjee *et al.*, 2014; Borchard *et al.*, 2014). The reason for this result is that the porous structure of biochar and the large specific surface area produces a strong adsorption capacity that allows for the adsorption of a large amount of NH_4 and NO_3, a reduction in nitrogen leaching, and an increase in total nitrogen content of soil (Lehmann *et al.*, 2003; Meng *et al.*, 2018), As a result, nitrogen remains in the root zone for a longer period, increasing its availability to plants, such increases in available nitrogen can have implications for soil fertility and nutrient uptake by the plant, which may benefit agricultural productivity (Jin *et al.*, 2019; Mukherjee *et al.*, 2014).

Conversely, our study also revealed a contrasting trend in available nitrogen concentrations for other biochar treatments. Specifically, the concentration of available nitrogen decreased in treatments involving 1% TSB250, 2.5% TSB250, 5% TSB250, and 5% TSB600. These findings align with the complex interactions observed in previous research regarding the impact of biochar on nitrogen dynamics in soil. (Lehmann *et al.*, 2003; Liu *et al.* 2021) reported that biochar produced at low temperatures can increase soil total organic carbon content especially biodegradable, enhance microbial activity, and stimulate the decomposition of biological, which could contribute to nitrogen immobilization and a decline in available nitrogen. Where our results show that the C:N ratios in the TBST 250 were significantly higher than those in the other temperatures (Table

3). On the other hand, the rate of biochar addition is another crucial factor that affects nitrogen availability in sandy soils. Studies by (Lehmann *et al*., 2003; Major *et al*., 2010) have demonstrated that excessive biochar application rates increased soil total organic carbon content more than the soil total nitrogen content can lead to nitrogen immobilization due to the high C:N ratio, where microorganisms utilize available nitrogen for biochar decomposition, reducing its immediate availability to plants.

Impact of tomato stems biochar Application on nitrogen uptake and nitrogen use efficiencies by wheat plant

The results of our study showed overall, tomato stems biochar (TSB) application had a positive influence on nitrogen uptake and nitrogen use efficiencies by wheat plants grown in the sandy soil. This was consistent with previous studies, which noted that biochar could increase nitrogen uptake and nitrogen use efficiency (Amin and Eissa, 2017; Cao *et al*., 2019; Omara *et al*., 2020). However, there were a couple of exceptions where TSB250 at levels 2.5% and 5% resulted in a slight decrease in nitrogen uptake compared to the control (Table 3).

The significant improvement of nitrogen uptake by plants result of the addition of biochar in this study is attributed to the improvement in N retention within the soil system by reducing the N loss (Zheng *et al*., 2013). A similar study explained that biochar soil amendment resulted in a 25% increase in nitrogen fertilizer uptake and reduced fertilizer loss by 9.5% (Huang *et al*. 2014; Omara *et al*., 2020). On the other hand, the improvement of wheat N uptake may be because the addition of biochar improves the soil's physical and chemical properties, making them more conducive to the growth of the roots (Huang *et al*., 2018; Ladha *et al*. 2008).

Similar to nitrogen uptake, biochar treatments generally at various levels and temperatures led to a significant increase in nitrogen use efficiency compared to the control, tomato stems biochar had a positive impact on nitrogen use efficiency by wheat plants, which is consistent with reports from several authors (Yao *et al*., 2012; Zheng *et al*., 2013; Mandal *et al*., 2016). Omara *et al*. (2020) found that applying biochar in combination with Nitrogen fertilizers led to increased nitrogen use efficiency by 13.5%. added biochar to soil led to improved crop nitrogen uptake, and nitrogen use efficiency by grown plants, this could be due to increased N retention or reduced nitrogen loss within soil amendment by biochar to improve crop nitrogen uptake, nitrogen use efficiency would be anticipated to enhance under such conditions. These results are consistent with (Zheng *et al*., 2013)

In addition, owing to the distinctive properties of biochar, including its pore structure and functional groups, it has the potential to act as a store for nutrients. Biochar can potentially allow the slow release of nutrients to the plant roots, thereby increasing nutrient utilization efficiency. This is achieved by enhancing the solubility of nutrients in water, retention, and consequently, their availability for plants (Ding *et al*., 2020; Liu *et al*., 2021; Haider *et al*., 2017). The improvement in plants' nitrogen uptake is related to the increase of Nitrogen bioavailability in soil as he explained (Zheng *et al.*, 2013). Yao *et al.* (2012) explained the increased retention of nitrogen is attributed to biochar's high sorption capacity. This offers favorable agroecological benefits such as reduced demand for Nitrogen fertilizers and minimizing nitrogen losses from soil.

The results also showed that nitrogen use efficiency by grown plants was the largest under TSB 400°C treatments but decreased with increasing temperature. These results are consistent with Javeed *et al.* (2021) found that biochar produced at low pyrolysis temperatures (300 and 400°C) is more effective in improving nitrogen use efficiency than at produced at higher pyrolysis temperatures (500 or 600°C). In another study, Guo *et al.* (2020) explained that biochar produced at a temperature of 350 °C had the highest values of nitrogen use efficiency by plant, then it decreased with increasing pyrolysis temperature. This underscores the importance of selecting the type of biochar, its concentration, and the pyrolysis conditions for improving nitrogen uptake and nitrogen use efficiency by plants.

Effects of tomato stems biochar application on several growth parameters

The results of our study demonstrate the positive impact of tomato stem biochar treatments on the growth and health of wheat plants in sandy soil. The significant increases in green biomass and dry biomass in response to biochar treatments are indicative of the ability of biochar to enhance plant growth. These findings are consistent with previous research on various crops and soil types (Amin, 2016; Naeem *et al.*, 2017; Zaheer *et al.*, 2021). In our study, the biochar level of 2.5% consistently outperformed other levels across all biochar types under this study, emphasizing the importance of the addition rate. Moreover, one of the key factors contributing to improved plant growth is the enhanced availability and uptake of nutrients (Ahmed *et al.*, 2019 Shen *et al.*, 2016). Biochar itself contains nutrients, and its addition to the soil increases the overall nutrient in the soil (Shen *et al.*, 2016; Naeem *et al.*, 2017; Wang *et al.*, 2015). The large surface area and high porosity of biochar improve water and nutrient retention, thus enhancing crop growth (Sial *et al.*, 2019; Major *et al.*, 2010). Our findings align with similar results found by (Suddick *et al.*, 2013; Major *et al.*, 2010).

The results also show that the application of biochar led to the increase in chlorophyll content in grown plants, a crucial indicator of plant health and photosynthesis efficiency is noteworthy. Also, TBC400 at 2.5% concentration resulted in the highest chlorophyll content, suggesting that biochar, particularly at this level, positively influenced the plant's ability to photosynthesize and produce chlorophyll. This finding is in line with the idea that biochar can enhance the synthesis of photosynthetic pigments (Chan *et al.*, 2009). Biochar amendments have the potential to improve soil physical properties and maintain long-term soil productivity (Wang *et al.*, 2015). They can increase soil organic matter, microbial activity, and nutrient retention, ultimately improving soil fertility and plant growth (Ahmed *et al.*, 2019; Hailegnaw *et al.*, 2019; Martinsen *et al.*, 2015). It is worth noting that the pyrolysis temperature and source of biochar can influence the concentration of nutrients released into amended soil (Naeem *et al.*, 2017; Wang *et al.*, 2015). An increase in organic matter in the soil due to the addition of biochar led to enhanced enzymatic activities and positively impacts crop growth (Haider *et al.*, 2020; Wang *et al.*, 2020). Biochar's ability to increase organic carbon in the soil promotes a healthy soil microflora and contributes to enhancing soil health and quality (Zhao *et al.*, 2006).

Conclusion

The study concludes that tomato stems biochar can be a promising agricultural improver for sandy soil properties and an important strategy in sustainable agriculture practices. The results showed addition of tomato stems biochar led to the enhancement of several sandy soil properties, nitrogen use efficiency as well plant growth parameters, while its effect on soil pH depended on the pyrolysis temperature. Higher pyrolysis temperatures (TSB400 and TSB600) increased soil pH, while lower temperatures (TSB250) led to a decrease in pH. Moreover, TSB400 and TSB600 treatments increased available nitrogen in sandy soil, while TSB250 treatments led to a decrease in available nitrogen. TSB400 at a 2.5% concentration appeared to be the most effective treatment in enhancing soil properties and nitrogen use efficiency as well as plant growth parameters. Finally, the choice of pyrolysis temperature and biochar dosage Plays a crucial role in determining required soil improvements. Higher pyrolysis temperatures (TSB400 and TSB600) generally led to more positive changes in soil properties, while lower pyrolysis temperatures (TSB250) had varying effects. Based on these results, we recommend applying TSB400 at 2.5% to sandy lands. However, further research is needed to conduct long-term field experiments to evaluate whether observed improvements are sustainable over multiple growing seasons and expand the scope to include other types of feedstocks for biochar production. This helps identify the most suitable feedstock for specific soil and crop combinations.

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تأثيرات درجات الانحلال الحراري لفحم سيقان الطماطم على خصائص التربة وكفاءة استخدام النيتروجين لنبات القمح المزروع في تربة رملية

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الملخص

بحثت هذه الدراسة في إمكانية استخدام الفحم الحيوي لسيقان الطماطم (TSB) المحضر عند ثلاث درجات انحلال حراري (250، 400، 600 درجة مئوية) كمحسن زراعي في تربة رملية لتحسين جودة التربة، كفاءة استخدام النيتروجين (NUE) ونمو القمح. تضمنت تجربة الاصص هذه المعاملات؛ الكنترول (بدون إضافة الفحم الحيوي)، 1% TSB250، 2.5% TSB250، 5% TSB250، 1% TSB400، 2.5% TSB400، 5% TSB400، 1% TSB600، 2.5% TSB600، 5% TSB6000، حيث تم تطبيق الفحم الحيوي في جرعات مختلفة (1، 2.5، 5% وزن/وزن). صممت هذه التجربة وفق التصميم العشوائي الكامل مع وجود ثلاث مكررات. بالمقارنة مع التربة غير المعدلة، أدى تطبيق TSB250 عند جميع الجرعات إلى انخفاض معنوي في درجة حموضة التربة، ولكن تطبيق TSB400 وTSB600 أدى إلى زيادة معنوية في درجة حموضة التربة. ادت تطبيقات TSB600 بنسبة 1 2.5% وكذلك TSB400 على جميع المستويات في زيادة النيتروجين الميسر في التربة بشكل معنوي، لكن النيتروجين الميسر في التربة الرملية انخفض معنوياً مع إضافة TSB250 بجرعات 2.5%، 5%. زادت الكتلة الحيوية الطازجة والجافة للقمح بشكل معنوي مع استخدام الفحم الحيوي لسيقان الطماطم. أدت إضافة TSB400، TSB600 بجميع الجرعات وكذلك 1% TSB250 إلى التربة الرملية إلى زيادات كبيرة في NUE لنبات القمح. زادت فعالية معالجات الفحم الحيوي لسيقان الطماطم على NUE بترتيب TSB400 > TSB600 > TSB250 وقد لوحظت أعلى قيم الكتلة الحيوية الطازجة والجافة وكذلك NUE من القمح عند معالجة TSB400 بنسبة 2.5٪. وبناء على هذه النتائج نوصي بتطبيق TSB400 بنسبة 2.5% على الأراضي الرملية.