Plant growth response of broad bean (*Vicia faba* L.) to biochar amendment of loamy sand soil under irrigated and drought conditions

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Abstract

The broad bean (*Vicia faba* L.) originated in the Near East, and is cultivated around the world, however, its cultivation is affected by drought stress in several central growing regions of the globe. The present study was designed to determine the effect of biochar on bean plant growth, acquisition of nitrogen (N), phosphorus (P), and potassium (K) and on soil nutrient contents under drought and irrigated conditions. Pyrolysis char from maize (MBC) at 2 and 4% concentrations was used for pot experiments. The shoot and/or root biomass of bean grown in soil amended with 2 and 4% MBC under irrigated condition was increased. Furthermore, increased nodule numbers of bean grown at 4% MBC amendment was observed under both irrigated and drought conditions. P and K uptake of plants under drought conditions increased by 14% and 23% under 2% MBC amendment, and by 23% and 34% under 4% MBC amendment as compared to plants grown without biochar application, respectively. This study demonstrated beneficial effects of biochar produced from maize on growth and nutrient uptake of broad bean, by improving the nodule formation and soil nutritional contents in a sandy loam soil.

Keywords Broad bean · Biochar · Drought stress · Nodulation · Plant nutrients

Introduction

Biochar is considered as a tool in climate change mitigation and also used as a soil amendment for improving soil health (Barrow 2012; Ma et al. 2019a). The improvement of plant growth and health in response to biochar application was reported by many studies (Graber et al. 2010; Albuquerque et al. 2015; Egamberdieva et al. 2016, 2019; Ma et al. 2019b). Positive effects were related to improved soil cation exchange capacity, nutrient retention, microbial activity and soil water holding capacity (Kolton et al. 2011; Yu et al. 2013; Soudek et al. 2016). Biochar was also reportedly used for the formulation of bacterial inoculants and provided potential applications in crop production (Egamberdieva et al. 2017). Moreover, Elad et al. (2010) demonstrated an induced systemic resistance in plants to various fungal pathogens after the application of biochar. In another study, however, biochar produced from maize caused root rot disease in lupin grown in loamy sand soil, whereas hydrochar improved plant growth and health (Egamberdieva et al. 2020). The response of soil enzymes to biochar also differ, as studies reported either an increase or a decrease after biochar application (Ameloot et al. 2013; Paz-Ferreiro et al. 2014). It has been stated that biochar effects depend on the technology and on the source of organic feedstock used for biochar production (Gul and Whalen 2016). Moreover, the interaction of biochar with plants and soils under different environmental conditions is another constraint for revealing distinctive effects. Therefore, knowledge on the response of plants to biochar amendment under different soil conditions is essential for resolving the best practices in the use of biochar.
Legumes are an important food source consumed in daily life and also used for feeding animals (Lüscher et al. 2014). Moreover, they are valuable components in crop rotation, increasing soil nitrogen content. However, drought has been reported as a main issue declining legume growth and yield (Bodner et al. 2015). The broad bean (Vicia faba L.) belongs to the family Fabaceae, originated in Mediterranean countries and Central Asia and cultivated around the world for food and oil production (Ammar et al. 2014). In Germany, faba bean is an almost negligible crop and its acreage was 16,000 hectares (FAO 2005). The cultivation of bean is mostly affected by abiotic stress such as drought in most legume growing regions. The water deficit in many bean cropping regions results in severe yield decline (Mukeshimana et al. 2014). Furthermore, the symbiotic performance of beans is restricted by drought, resulting in decreased nodule (Loss and Siddique 1997). Thus, the knowledge on the effect of different biochar types and application rates on plant growth and soil nutrient availability provides important guidance for future field applications. The present study was designed to assess the effect of biochar on bean growth, nitrogen (N), phosphorus (P), and potassium (K) acquisition under drought and irrigated soil conditions.

Material and methods

Seeds of the broad bean (V. faba L. var. Gubbestad) were obtained from the Leibniz Centre for Agricultural Landscape Research e.V. (ZALF) Müncheberg, Germany, and the biochar was from the Leibniz-Institute for Agrartechnik Potsdam-Bornim e.V. (ATB), Germany. The biochar was produced from maize biochar (MBC) and by application of biochar on legume growth and physiological properties. For example, the application of biochar increased the root and shoot dry mass, as well as the number and pods of common bean (Phaseolus vulgaris L.) (da Silva et al. 2017). Berihun et al. (2017) found increased seed germination, root and shoot growth, number of seeds and grain yield of garden pea (Pisum sativum L.) by application of biochar produced from corncob. Notably, both biochar concentrations improved the plant growth, and nodule number of bean under drought conditions. The root biomass of bean was increased significantly by 58 and 68% under 2 and 4% MBC amended soil and drought conditions, respectively.

Results and discussion

The root and shoot of bean responded differently to MBC concentrations. The shoot and root biomass of bean under irrigated soil condition were affected by MBC soil amendments at 2 to 4%, being increased by 17 and 11% for shoot and 13 and 37% for root respectively (Fig. 1). The root dry weight of bean was significantly increased by MBC compared to soil without biochar addition. The root growth was increased by 38% and 28% by MBC amendment at 2% and 4% concentration respectively, when compared to control plants grown in soil without biochar addition (Figs. 1, 2). There are numerous reports on the positive effect of biochar on legume growth and physiological properties. For example, the application of biochar increased the root and shoot dry mass, as well as the number and pods of common bean (Phaseolus vulgaris L.) (da Silva et al. 2017). Berihun et al. (2017) found increased seed germination, root and shoot growth, number of seeds and grain yield of garden pea (Pisum sativum L.) by application of biochar produced from corncob. Notably, both biochar concentrations improved the plant growth, and nodule number of bean under drought conditions. The root biomass of bean was increased significantly by 58 and 68% under 2 and 4% MBC amended soil and drought conditions, respectively (Fig. 1). The positive effect of biochar on plant growth was demonstrated in many other reports (Akhbar et al. 2015), e.g. for sunflower (Panneque et al. 2016), tomato (Aghna et al. 2017) and rapeseed (Bamming et al. 2016). Moreover, growth increment was explained by improved soil water holding capacity by biochar amendment (Basso et al. 2013).

The nodule numbers of bean were 23.6 and 7.6 in plants grown in soil without biochar under irrigated and drought conditions, while 4% MBC char addition to soil increased...
nodule numbers to 36.6 and 16.3 per plant, respectively (Fig. 3). There are several explanations discussed on the beneficial effect of biochar on plant nodule formation. The biochar pores where bacteria colonize, play a role in the protection of microbes from various stresses, providing better gas exchange and nutrient supply (Iijima et al. 2015). In another study it was reported that biochar amendment provided favourable conditions for microbial proliferation and survival (Kolton et al. 2011). The nodule number of chickpea grown in soil amended with MBC was also increased, thereby promoting plant growth and nutrient concentrations (Egamberdieva et al. 2019).

The nutrient uptake of beans was also affected by the biochar concentrations under both conditions. The N and K contents of plants were increased significantly (P < 0.05) by 17 and 26% under 2% MBC amended soil and irrigated conditions, respectively. The P concentrations in plant tissue were increased (10%) only in soil amended with 4% MBC. The N uptake of bean was increased in 2% MBC amended soil only. Similar results were reported by Rondon et al. (2007) for bean, showing higher N concentrations in plant tissue grown in biochar-amended soil. Similar observations...
were also reported by Wang et al. (2018) where plant growth and K uptake in soybean increased in soil amended with bamboo biochar. According to Prendergast-Miller et al. (2011), biochar may contribute to the availability of N and P for plants through inducing soil biological activity and mineralization (Prendergast-Miller et al. 2011). Biochar derived from willow woodchips improved P uptake of plants compared to non-amended soil (Shen et al. 2016). Higher concentrations of P and K in plant tissues were observed for MBC amended soil under drought conditions, increasing by 14% and 23% under 2% MBC char, and by 23 and 34% under 4% MBC char as compared to plants grown on soil without biochar application, respectively (Table 1). In previous reports, it was indicated that biochar amendment of soils affects the availability of K for plants (Rogovska et al. 2014) and this effect was due to improved soil water holding capacity (Abel et al. 2013; Bruun et al., 2014).

MBC under drought and irrigated conditions affected the N, P, and K concentrations in soil (Table 2). Higher concentrations of soil P and K were detected in soil amended with 2 and 4% MBC both under drought and irrigated conditions. Several studies reported that biochar amendment affects the availability of P and K in soil, depending on physicochemical properties of biochar (Joseph et al. 2010; Rogovska et al. 2014; Farrell et al. 2013). In our study, MBC contains high concentrations of K and this could be related to the increased K concentration in soil.

In this study, we have demonstrated that soil amendment with MBC had a positive effect on plant growth, nodule number, as well as P and K acquisition of broad bean, which was more pronounced under the drought conditions as compared to the irrigated soil. The soil P and K concentrations were also increased by MBC application which supplies additional sources of nutrients for plant nutrition. Our results imply that maize biochar is a promising practical approach to improve growth, nutrient acquisition, and yield of legumes under hostile environments in a sustainable way.

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Table 1 Nutrient concentrations in bean plant tissue grown in soils after application of maize biochar (MBC, 2 and 4%) under irrigated and drought conditions

|          | Irrigated |          | Drought |          |
|----------|-----------|----------|----------|----------|
|          | N         | P        | K        | N        | P        | K        |
| Control  | 1.83 ± 0.14 | 0.26 ± 0.02 | 1.60 ± 0.05 | 2.11 ± 0.14 | 0.29 ± 0.02 | 1.78 ± 0.09 |
| MBC 2%   | 2.16* ± 0.09 | 0.28 ± 0.01 | 2.06* ± 0.07 | 2.30 ± 0.10 | 0.33* ± 0.02 | 2.20* ± 0.05 |
| MBC 4%   | 2.05 ± 0.13 | 0.29 ± 0.01 | 2.26* ± 0.17 | 2.29 ± 0.09 | 0.31* ± 0.02 | 2.40* ± 0.13 |

Plants were grown for 30 days after the start of the experiment. The asterisks indicate significant differences from the control at P < 0.05

Table 2 Soil nutrient concentrations after application of maize biochar (MBC, 2 and 4%) under irrigated and drought conditions

|          | Irrigated |          | Drought |          |
|----------|-----------|----------|----------|----------|
|          | N (%)     | P        | K        | N (%)     | P        | K        |
|          | mg 100 g⁻¹ soil | mg 100 g⁻¹ soil | mg 100 g⁻¹ soil | mg 100 g⁻¹ soil | mg 100 g⁻¹ soil |
| Control  | 0.086 ± 0.01 | 6.60 ± 0.28 | 5.50 ± 0.89 | 0.080 ± 0.01 | 7.37 ± 0.76 | 6.61 ± 0.88 |
| MBC 2%   | 0.093 ± 0.01 | 8.91* ± 0.38 | 9.30* ± 0.35 | 0.107 ± 0.02 | 8.23* ± 0.44 | 12.28* ± 0.84 |
| MBC 4%   | 0.089 ± 0.01 | 9.91 ± 0.87 | 13.40* ± 0.96 | 0.120* ± 0.01 | 9.06* ± 0.20 | 15.83* ± 0.58 |

Plants were grown for 30 days after the start of the experiment. The asterisks indicate significant differences from the control at P < 0.05
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