Environmental Sustainability (2020) 3:319–324
https://doi.org/10.1007/s42398-020-00116-y

SHORT COMMUNICATION

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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Received: 27 April 2020 / Revised: 18 July 2020 / Accepted: 21 July 2020 / Published online: 4 August 2020

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; Alburquerque 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.

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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 nodulation (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 at a pyrolysis temperature of 600 °C for 30 min. The characteristics of maize biochar (MBC) are as follows: carbon (C)—75.1%, nitrogen (N)—1.65%, phosphorus (P)—5.26 and potassium (K)—31.12 (g/kg fresh weight), pH—9.89 and electrical conductivity—3.08 (Reibe et al. 2015). The soil was taken from the experimental field site of ZALF. The soil pH is 6.2, and contains 0.50% C, 0.07% N, 0.03% P, and 1.25% K (Egamberdieva et al. 2019).

The pots were filled with 800 g of air-dried soil for the plant growth experiments. The crushed biochar (particle size < 3 mm) was added at 2 and 4% concentrations and mixed with soil. The following three treatments were set up; (1) control—soil without MBC, (2) soil amended with 2% MBC and (3) soil amended with 4% MBC. Three seeds were sown in each pot, and after one week, the seedlings were thinned to one plant per pot. Four replicate pots were used for all treatments, and pots were arranged in a randomized complete block design.

Plants were grown in two different soil conditions, (1) well-watered (80% soil moisture) and (2) under drought (40% soil moisture) in a greenhouse located at ZALF. Plants were irrigated with tap water and the soil moisture levels were monitored using the commercially available UMP-1 BT soil moisture sensor (Umwelt-Geräte-Technik GmbH, Germany) (Egamberdieva et al. 2019). The temperature was maintained at 24 °C/16 °C (day/night) at a humidity of 50–60%. The plants were grown for 30 days, then at harvest the root and shoots were separated, washed and oven-dried. The dry biomass and nodule numbers were determined. The total nitrogen (N) of the plant tissue and soil samples were determined by the dry combustion method (Nelson and Sommers 1982) using an elemental determinator (TruSpec CNS). P and K were analyzed with an inductively coupled plasma - optical emission spectrometry (ICP-OES) (iCAP 6300 Duo). Data were tested for statistical significance using the analysis of variance package included in Microsoft Excel 2010. Mean comparisons were conducted using the least significant difference (LSD) test ($P = 0.05$).

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 ($P < 0.05$) increased in soil amended with 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 (Akhtar et al. 2015), e.g. for sunflower (Paneque et al. 2016), tomato (Agbna et al. 2017) and rapeseed (Bamminger 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

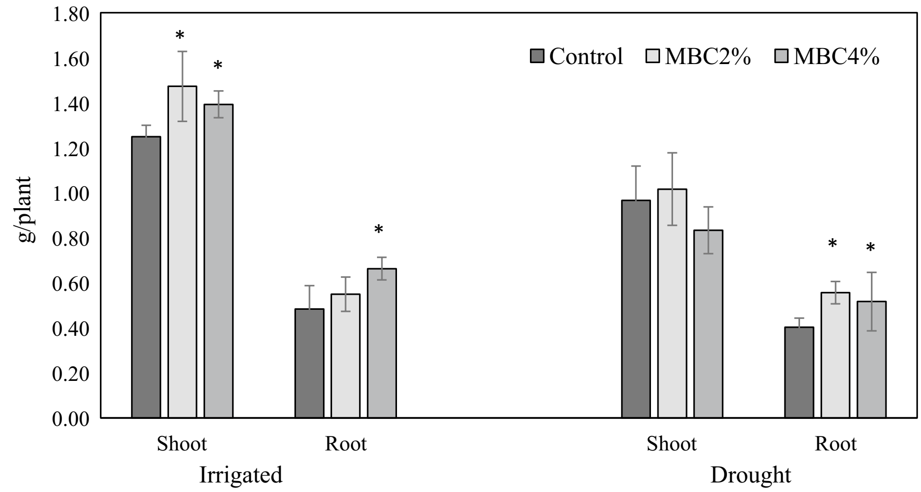

Fig. 1 Shoot and root growth of broad bean grown in soil amended with maize biochar (MBC, 2% and 4%) under irrigated and drought conditions. Column means with an asterisk are significantly different from the control at $P<0.05$

Fig. 2 The effect of 2% maize biochar (MBC) on plant growth of broad bean in loamy sand soil. Plants were grown in soil amended with 2% MBC and in soil without biochar for 30 days

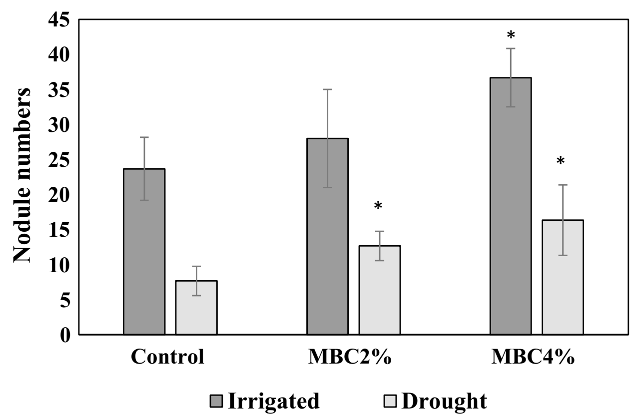

Fig. 3 The nodule number of broad bean grown in soil amended with maize biochar (MBC, 2% and 4%) under irrigated and drought conditions. Column means with an asterisk are significantly different from the control at $P<0.05$

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

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	
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 $P < 0.05$

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 availablility 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.

Acknowledgements Open Access funding provided by Projekt DEAL.

References

Abel S, Peters A, Trinks S, Schonsky H, Facklam M, Wessolek G (2013) Impact of biochar and hydrochar addition on water retention and water repellency of sandy soil. Geoderma 202–203(410):183–191

Agbna GHD, Dongli S, Zhipeng L, Elshaikh NA, Guangcheng S, Timm LC (2017) Effects of deficit irrigation and biochar addition on the growth, yield, and quality of tomato. Sci Hortic 222:90–101

Akhtar SS, Andersen MN, Liu F (2015) Residual effects of biochar on improving growth, physiology and yield of wheat under salt stress. Agric Water Manag 158:61–68

Alburquerque JA, Cabello M, Avelino R, del Campillo VBMC, Torrent J (2015) Plant growth responses to biochar amendment of Mediterranean soils deficient in iron and phosphorus. J Plant Nutr Soil Sci 178:567–575

Ameloot N, De Neve S, Jegajeevagan K, Yildiz G, Buchan D, Nkwain Y Funkuin, Prins W, Bouckaert L, Sleutel S (2013) Short-term CO_2 and N_2O emissions and microbial properties of biochar amended sandy loam soils. Soil Biol Biochem 57:401–410

Ammar MH, Anwar F, El-Harty EH, Migdadi HM, Abdel-Khalik SM, Al-Faifi SA, Farooq M, Alghamdi SS (2014) Physiological and yield responses of faba bean (*Vicia faba* L.) to drought stress in managed and open field environments. J Agron Crop Sci 201:280–287

Bamminger C, Poll C, Sixt C, Högy P, Wüst D, Kandeler E, Marhan S (2016) Short-term response of soil microorganisms to biochar addition in a temperate agroecosystem under soil warming. Agric Ecosyst Environ 233:308–317

Barrow CJ (2012) Biochar: potential for countering land degradation and for improving agriculture. Appl Geogr 34:21–28

Basso AS, Miguez FE, Laird DA, Horton R, Westgate M (2013) Assessing potential of biochar for increasing water-holding capacity of sandy soils. Gcb Bioenergy 5(2):132–143

Berihun T, Tolosa S, Tadele M, Kebede F (2017) Effect of biochar application on growth of garden pea (*Pisum sativum* L.) in acidic soils of Bule Woreda Gedeo zone southern Ethiopia. Int J Agron. https://doi.org/10.1155/2017/6827323**(Article ID 6827323)**

Bodner G, Nakhforoosh A, Kaul HP (2015) Management of crop water under drought: a review. Agron Sustain Dev 35:401–442

Bruun EW, Petersen CT, Hansen E, Holm JK, Hauggaard-Nielsen H (2014) Biochar amendment to coarse sandy subsoil improves root growth and increases water retention. Soil Use Manag 30(1):109–118

da Silva ICB, Fernandes LA, Colen F, Rural RASC, Maria S (2017) Growth and production of common bean fertilized with biochar. Ciência Rural Santa Maria 47:11

Egamberdieva D, Alaylar B, Shurigin V, Ma H, Wirth S, Müller EHM, Reckling M, Bellingrath-Kimura SD (2020) The endophytic bacteria decrease susceptibility of white lupin (*Lupinus albus* L) to fusarium wilt disease in soil amended with biochar produced from wood. Microorganisms 8(4):496

Egamberdieva D, Li L, Ma H, Wirth S, Bellingrath-Kimura SD (2019) Soil amendments with different maize biochars, to varying degrees, improve chickpea growth under drought by improving symbiotic performance with *Mesorhizobium ciceri* and soil biochemical properties. Front Microbiol. https://doi.org/10.3389/fmicb.2019.02423

Egamberdieva D, Ma H, Reckling M, Wirth S, Bellingrath-Kimura SD (2018) Potential effects of biochar-based microbial inoculants in agriculture. Environ Sustain. https://doi.org/10.1007/s42398-018-0010-6

Egamberdieva D, Reckling M, Wirth S (2017) Biochar-based inoculum of *Bradyrhizobium* sp. improves plant growth and yield of lupin (*Lupinus albus* L.) under drought stress. European Journal of Soil Biology 78:38–42

Egamberdieva D, Wirth S, Behrendt U, Abd-Allah EF, Berg G (2016) Biochar treatment resulted in a combined effect on soybean growth promotion and a shift in plant growth promoting rhizobacteria. Front Microbiol 7:209. https://doi.org/10.3389/fmicb.2016.00209

Elad Y, David DR, Harel YM, Borenshtein M, Kalifa HB, Silber A, Graber ER (2010) Induction of systemic resistance in plants by biochar, a soil-applied carbon sequestering agent. Phytopathology 100:913–921

Farrell M, Macdonald LM, Butler G, Chirino-Valle I, Condron LM (2014) Biochar and fertiliser applications influence phosphorus fractionation and wheat yield. Biol Fertil Soils 50:169–178

FAO (Food and Agriculture Organization) (2005). http://www.faostat.fao.org. Accessed Feb 2007

Graber ER, Meller Harel Y, Kolton M, Cytryn E, Silber A, David DR, Tsechansky L, Borenshtein M, Elad Y (2010) Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. Plant Soil 337:481–496

Gul S, Whalen JK (2016) Biochemical cycling of nitrogen and phosphorus in biochar-amended soils. Soil Biol Biochem 103:1–15

Iijima M, Yamane K, Izumi Y, Daimon H, Motonaga T (2015) Continuous application of biochar inoculated with root nodule bacteria to subsoil enhances yield of soybean by the nodulation control using crack fertilization technique. Plant Prod Sci 18(2):197–208

Joseph SD, Camps-Arbestain M, Lin Y, Munroe P, Chia CH, Hook J, van Zwieten L, Kimber S, Cowie A, Singh BP, Lehmann J, Foidl N, Smernik RJ, Amonette JE (2010) An investigation into the reactions of biochar in soil. Aust J Soil Res 48:501–515

Kolton M, Meller Harel Y, Pasternak Z, Graber ER, Elad Y, Cytryn E (2011) Impact of biochar application to soil on the root-associated bacterial community structure of fully developed greenhouse pepper plants. Appl Environ Microbiol 77:4924–4930

Loss SP, Siddique KHM (1997) Adaptation of faba bean (*Vicia faba* L.) to dryland Mediterranean-type environments I. Seed yield and yield components. Field Crops Res 53:17–28

Lüscher A, Mueller-Harvey I, Soussana JF, Rees RM, Peyraud JL (2014) Potential of legume-based grassland-livestock systems in Europe: a review. Grass Forage Sci 69:206–228

Ma H, Egamberdieva D, Wirth S, Li Q, Omari RA, Hou M, Bellingrath-Kimura SD (2019a) Effect of biochar and irrigation on the interrelationships among soybean growth, root nodulation, plant p uptake, and soil nutrients in a sandy field. Sustainability 11(23):6542

Ma H, Egamberdieva D, Wirth S, Bellingrath-Kimura SD (2019b) Effect of biochar and irrigation on soybean-rhizobium symbiotic performance and soil enzymatic activity in field rhizosphere. Agronomy 9(10):626

Mukeshimana G, Butare L, Cregan PB, Blair MW, Kelly JD (2014) Quantitative trait loci associated with drought tolerance in common bean. Crop Sci. 54(3):923–938

Nelson DW, Sommers LE (1982) Total carbon, organic carbon and organic matter. In: Methods of soil analysis; Part 2. Page AL. Ed. ASA; SSSA, Madison, WI, USA, pp 539–579

Paz-Ferreiro J, Fu SL, Méndez A, Gascó G (2014) Interactive effects of biochar and the earthworm *Pontoscolex corethrurus* on plant productivity and soil enzyme activities. J Soils Sediments 14:483–494

Paneque M, José M, Franco-Navarro JD, Colmenero-Flores JM, Knicker H (2016) Effect of biochar amendment on morphology, productivity and water relations of sunflower plants under non-irrigation conditions. Catena 147:280–287

Prendergast-Miller MT, Duvall M, Sohi SP (2014) Biochar-root interactions are mediated by biochar nutrient content and impacts on soil nutrient availability. Europ J Soil Sci 65(1):173–185

Reibe K, Götz KP, Ross CL, Döring TF, Ellmer F, Ruess L (2015) Impact of quality and quantity of biochar and hydrochar on soil collembola and growth of spring wheat. Soil Biol Biochem 8:84–87

Rogovska N, Laird D, Rathke SJ, Karlen DL (2014) Biochar impact on Midwestern Mollisols and maize nutrient availability. Geoderma 230–231:34–347

Rondon MA, Lehmann J, Ramírez J, Hurtado M (2007) Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. Biol Fertil Soils 43(6):699–708

Soudek P, Rodriguez Valseca IM, Petrova S, Song J, Vanek T (2016) Characteristics of different types of biochar and effects on the toxicity of heavy metals to germinating sorghum seeds. J Geochem Explor 182:157–165

Shen Q, Hedley M, Camps Arbestain M, Kirschbaum MUF (2016) Can biochar increase the bioavailability of phosphorus? J Soil Sci Plant Nutr 16(2):268–286

Wang C, Alidousta D, Yng X, Isoda A (2018) Effects of bamboo biochar on soybean root nodulation in multi-elements contaminated soils. Ecotoxicol Environ Saf 150:62–69

Yu OY, Raichle B, Sink S (2013) Impact of biochar on the water holding capacity of loamy sand soil. Int J Energy Environ Eng 4:44