Moroccan Journal of Agricultural Sciences
Vol 2 No 2 (2021): (June 2021)
Crop Production and Environment

Biochar particles size influenced the yield and water productivity of two mint (Mentha sp.) varieties under drip irrigation

Mariam A. AMER — Department of Bioengineering Research, Agricultural Engineering Research Institute, Agricultural Research Center, Dokki, Egypt
Tahany NORELDIN — Department of Water Requirement and field Irrigation Research; Soils, Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt
Alia AMER — Department of Medicinal and Aromatic plants, Horticultural Research Institute, Agricultural Research Center, Dokki, Egypt

In a two-year experiment conducted in 2019 and 2020, evaluation of the interaction between biochar particle sizes (without application (B1), <1 mm (B2), 6.60-9.50 mm (B3) and >13 mm (B4)) and irrigation treatments (120 (I1), 100 (I2) and 80% (I3) ETo) on yield, water use efficiency (WUE) and water productivity (WP) of two mint varieties (spearmint (V1) and peppermint (V2)) was done in the new soil of El-Behira Governorate under drip system. The results showed that, in both cuts, application of I1 and B4 increased the fresh yield by an average of 16.6 % for varieties and seasons, compared to other treatments. The highest oil yield was increased by an average of 28.0% for varieties and seasons under B2 and I3, compared to other treatments. The highest applied irrigation water was 11655 m^3/ha under I1 averaged over varieties and seasons, which attained the highest yield under the application of the four biochar treatments. Application of I2 and B2 attained the highest values of WUE, namely 3.29 and 2.75 kg/m^3 for V1 and V2, respectively averaged over seasons. The highest values of WP were also found under I2 and B2, namely 2.80 and 2.34 kg/m^3. In conclusion, application of B2 could relieve the effect of water deficiency and increase both WUE and WP for both mint varieties.

Keywords: Biochar particles size, spearmint (*Mentha spicate*), peppermint (*Mentha piperita* L.), water use efficiency, water productivity

INTRODUCTION

Biochar is a carbon rich substance that could be used to improve the quality of agricultural soils (Glaser et al., 2002). Biochar is produced from the thermal-chemical alteration of biomass that contains organic compounds by pyrolysis process (Lehmann, 2009). Several benefits have been recorded after the application of biochar to the soil. It has a potential to alter soil hydraulic properties and to drive shifts in water retention (Liu et al., 2017). The porous structure of biochar can lower the bulk density of soil, thus increasing water retention. This ability to improve the water-holding capacity illustrates its application in regions where water deficit is a limiting factor for crop production (Karhu et al., 2011). It could affect plant growth by adjusting soil hydrologic properties (Githinji, 2013 and Herath, 2013), nutrient availability (Glaser and Birk, 2012; Dai et al., 2017), which will have a positive effects on crops productivity (Lehmann and Joseph, 2009). The effects on the chemical and physical properties of soil are dependent on the biochar amount, pyrolysis temperature, biomass type, and biochar particle size (Blanco-Canqui 2017; Wang et al., 2018). The positive effects of application of biochar to the soil have been studied by many investigators in Egypt (Ali, 2018; Mohmed et al., 2017; Abdelraouf et al., 2017). However, there were no researches done on its application to medicinal crops.

The genus Mentha (common mint) includes 25–30 species grown under cultivation from tropical to temperate climate of America, Europe, China, Brazil, India, Australia, and South Africa (Mustafa et al., 2005). About 2000 tons of the world's essential oil come from various species of the genus Mentha, which is the second most important group of oil plants after citrus plants (Sadowska et al., 2020). In Egypt, there are several species of common mint, such as spearmint (Mentha spicata L.), and peppermint (Mentha piperita L). These species are commercially grown for their herbs and essential oil content. They are belongs to the Labiatae family spearmint herb and its volatile oil are used as flavoring agents for several kinds of products and beverages, carminative, mouth preparations, gargles, tooth pastes and pharmaceuticals, such as sore throat, diarrhea, tooth aches, cramp and indigestion, as well as in massaging lotions for aching muscles and rheumatic joints (Kashyap and Sharma, 2005). The mint plants are considered as a succulent, multi-cut crops that has a high-water requirements during its active growth period in summer months. It can be easily adapted to a variety of climate and soil conditions (Scora and Chang,1997). However, Veronese et al., (2001) mentioned that mint and mint oil yield are modified by biotic and abiotic stresses. Many investigations have been done in Egypt to determine the required management practices for mint to attain higher yield (Amer et al., 2019 and Arafa et al., 2017). However, there was no research done on the effect of application of different biochar particle size on mint yield.

Egypt is characterized by having limited water resources; therefore, it is crucial to improve water management for the cultivated crops through improving water use efficiency and water productivity. Furthermore, expansion in cultivating new lands in Egypt in new reclaimed soil necessitates the use of soil amendments that can help in increasing water holding capacity and reducing water lost to deep percolation to groundwater. Amending soil by biochar has been suggested as a strategy to improve long-term productivity and increase nutrient and water use efficiency (Sarong and Orge, 2015). The effect of biochar application was studied before in Egypt for several crops (Khalifa and Elareny, 2020; Ibrahim et al., 2019; Abdelraouf et al., 2017).However, there was no research done on the effect of application of different biochar particle size on irrigation water saving applied to mint varieties.

Therefore, the objective of this study was to determine which particle size of biochar can attain the highest yield of fresh leaves and oil yield, as well as the highest water use efficiency and water productivity of two mint varieties grown under drip irrigation system.

MATERIALS AND METHODS

Field layout

Two field experiments were conducted during two successive seasons of 2019 and 2020 at the Experimental Farm of South Tahrir Horticulture Research Station, Ali Mubarak village, El-Bustan Area, El-Behira Governorate, (31°02′N and 30° 28′E and 6.7 m a.s.l.). The average meteorological values during the experimental period is given in Table 1. It was obtained from the following: https://power.larc.nasa.gov/data-access-viewer/. Evapotranspiration (ETo, mm/day) was calculated using BISm model (Snyder et al., 2004).

Some soil physical and chemical properties of the experimental site are shown in Table 2. Chemical soil analysis was conducted by the standard methods described by Tan (1996). The chemical analysis of the irrigation water indicated that electrical conductivity (EC) was 0.50 dS/m at 25 ºC and pH value was 7.5 (Page et al., 1982).

The soil moisture constants at the experimental site at the depth of 60 cm are presented in Table 3 according to Stackman (1966).

The experiment was arranged in a split-split plot design with four replicates. The main plots were assigned to irrigation treatments, namely 120 % ETo (I1), 100 % ETo (I2), 80% ETo (I3). The varieties were assigned to the sub-plots, namely V1 for spearmint (V1) and peppermint (V2). The sub-sub plots were assigned to biochar particles size treatments, namely B1 (without biochar), B2 (fine <1 mm), B3 (medium 6.60 - 9.50 mm), B4 (coarse >13 mm).

Biochar production and particle sizes preparation

Biochar is commercially produced by drying different agricultural residues at 105 °C in a dry oven, followed by 120 min of pyrolyzation in the reactor made from carbon steel sheet with 0.8 mm thickness, which has a dimension of 306.5× 300 × 305.5 mm length, width and height, respectively at 450 °C in the absence of oxygen. The reactor was hermetically sealed. The pyrolysis process was performed by Faculty of Agricultural Engineering, Cairo University in this metal reactor, saturating the sample with N2 and raising the temperature 10 °C every minute during the first 30 min and 20 °C per minute until reaching the desired temperature. Ash content, Moisture content, Bulk density and carbon, nitrogen, and hydrogen content of biochar were reported in Liu et al. (2016). The chemical properties of the biochar were: C=55.8, N=2.66, H= 1.02 %, ash=16.8 %, moisture content= 6%, bulk density= 0.57.

In order to scan the thin film of dry biochar and get an impression of the pore sizes, we visualized the morphology of the chars by electron-microscopic images (in the Faculty of Agriculture at the Mansoura University, Egypt), using SEM scanning electron micrographs “microscope” (SEM) HITACHI S-3400, Japan).

The biochar was sieved using sieve shaking machine, model number 62,020 into three sizes. Figure 1 Presented the three used particle sizes of biochar.

Field Experiment

In this study, the recommended doses of fertilization program were supplied in 3 times. In land preparation, Calcium super phosphate (15.5% P2O5) at the rate of 960 kg/ha was added. Potassium was applied in the form of potassium sulfate (48% K2O) at the rate of 360 kg/ha. The K fertilizer was applied in 2 equal doses, the first dose is after one month of planting, while the second is after two months from planting. Ammonium sulphate (20.6 %N) was applied at the rate of 1.080 kg/ha in equal 3 doses, the first was applied after one month of planting, while the second was two months after planting and the third was after the first cut. The stolons of the two mint varieties (15–20 cm in length with 10-12 leaves) were obtained from the Farm of Medicinal and Aromatic Plants Department, El-Kanater El- Khairiya, Kalubeia Governorate, Egypt. Stolons were transplanted 25 cm a part on 15th of April for each season. The three biochar particle sizes were incorporated into the soil at the rate of 3.0 t/ha in a hill of 1 inch under mint seedlings. Furthermore, all the recommended cultural practices were timely implemented until harvest.

Irrigation water was applied every three days using drip irrigation system. It was a surface drip including an irrigation pump (50 hp) connected to sand and screen filters, the conveying pipeline system consists of a 63 mm PVC main line connected to 50.8 mm PVC sub-main line. The drip lateral lines of 16 mm diameter are connected to the sub-main line. Each lateral line is 20 m long and spaced at 0.7 m on the sub-main and is equipped with build-in emitters of 2 L/h discharge rate spaced at 0.3 m on the lateral lines.

Vegetative and yield measurements

Two cuts were taken during the two growing seasons at 60% flowering: the first one was on 1st July and the second one was on 1st September, where all the above ground plant parts were cut at the height of 10 cm. At harvest, plant samples were randomly collected from all treatments, where plant height (cm) and fresh weight (ton/ha) were measured.

Essential oil percentage were determined at the laboratory of Cultivation and Production of Medicinal and Aromatic Plants, Agricultural Research Centre (ARC), Dokki, Cairo, Egypt. 100 g of the herb fresh weight was used to determine oil content percentage by hydro distillation for 3 hours using a Clevenger type apparatus according to the methods described by Guenther (1961). Essential oil yield (ml/plant) were calculated by multiplying the average fresh weight of plant by the average of oil percentage. The oil yield per plant was calculated from the following equation:

Oil yield/plant = plant fresh weigh (g) × oil (%)

Crop water use

Applied irrigation water

The amounts of applied irrigation water were calculated according to the equation given by Vermeiren and Jopling (1984) as follows:

where:

AIW= depth of applied irrigation water (mm).

ETo = reference evapotranspiration (mm d-1).

I = irrigation intervals (days).

Ea= irrigation application efficiency of the irrigation system.

LR= leaching requirements (equal 1.0).

The values of ETo and water consumptive use were calculated using BISm model (Snyder et al., 2004).

Water use efficiency (WUE)

Water use efficiency for each mint variety was calculated according to Stanhill (1986) as followed:

Crop water productivity (WP)

Crop water productivity of mint was calculated according to the equation presented by Zhang (2003) as follows:

Statistical analysis

The obtained data were statistically analyzed according to the technique of analysis of variance (ANOVA) in split-split plot design as published by Gomez and Gomez (1984). Means of the treatment were compared by the least significant difference (LSD) at 5% level of significance as developed by Waller and Duncan (1969).

RESULTS

Biochar scanning electron-microscopic images

Figure 2 presents the scanning electron micrographs (SEM) of the agricultural waste biochar micro particles. The surface morphologies of all the biochar particles were highly heterogeneous and structurally complex, with abundant and regularly arranged, circular, tubular grooves, making it porous of different diameters. Biochar presents an extremely complex network of pores and channels, together with a fibrous surface. Pores of wide size ranges are created because of the organic and volatile matters escape from feedstock during pyrolysis, which is also associated with change in physical properties and elemental composition of the produced char. In addition, in Figure 2 A, fine biochar particles <1 mm showed thinner and less lignified cell as well as less evidence of macrospores, respectively. While, Figure 2 B for medium biochar particles (6.60 - 9.50 mm) and Figure 2 C is for the coarse biochar particles with >13 mm showed a large number of closely spaced macro pores spread across biochar surface, which is clearly seen through SEM image.

Mint varieties performance under interaction between irrigation and biochar particle sizes treatments

Effect on plant height and fresh weight

The result in Table 4 showed that plant height and fresh weight of mint were significantly affected by irrigation treatments, varieties, the interaction between irrigation and varieties, biochar and the interaction between biochar and irrigation in both growing seasons. With respect to interaction between biochar and varieties, it only had a significant effect on plant height in the second cut in both seasons and on fresh yield in the first cut in the first seasons and on both cuts in the second seasons. The interaction between irrigation, biochar and varieties had a significant effect only on the second cut of plant height in the first season and on the first cut of fresh weight in both seasons.

The results in Table 4 also showed that the highest plant height and fresh weight values of both varieties were obtained under application of I1 and B4 in both seasons, where V1 had higher values than V2. The lowest values were obtained under I3 and without biochar in both seasons. Furthermore, the results showed that application of B4 under I1 increased plant height by 12.5 and 12.5 % for V1 and V2, respectively averaged over the two growing seasons,compared to application of I1 and B1. For I2, application of B2 increased plant height by 13.3 and 11.2 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I2 and B1. Similarly, application of B2 under I3 increased plant height by 16.2 and 15.9 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I3 and B1.

Table 4 also showed a similar trend for fresh weight values under the interaction between I and B, where the application of B4 under I1 increased it by 9.03 and 8.11 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I1 and B1. Under application of I2, B2 application increased fresh weight by 16.1 and 15.5 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I2 and B1. Similarly, application of B2 under I3 increased fresh weight by 17.8 and 16.9 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I3 and B1.

Effect on percentage of essential oil and oil yield per plant (ml/plant)

The percentage of essential oil and oil yield of mint varieties were significantly affected by all the studies treatments and the interaction between them, except in the second cut in the second season (Table 5).The results in Table 5 also showed that the highest percentage of essential oil and oil yield values of both varieties were obtained under application of I1 and B4 in both seasons. The lowest values were obtained under I3 and without biochar in both seasons. Furthermore, the results showed that application of B4 under I1 increased percentage of essential oil by 5.28 and 4.23 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I1 and B1. For I2, application of B2 increased percentage of essential oil by 11.0 and 11.3 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I2 and B1. Similarly, application of B2 under I3 increased percentage of essential oil by 14.2 and 12.7 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I3 and B1.

Table 5 also showed a similar trend for oil yield values under the interaction between I and B, where the application of B4 under I1 increased it by 14.7 and 12.4 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I1 and B1. Under application of I2, B2 application increased oil yield by 28.84 and 28.1 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I2 and B1. Similarly, application of B2 under I3 increased oil yield by 34.8 and 31.9 % for V1 and V2, respectively averaged over the two growing seasons, compared to application of I3 and B1.

Applied Irrigation Water (AIW)

The results in Table 6 indicated that the applied irrigation water for mint ranged between 11640 to 7304 m3/ha in 2019 and 11670 to 7322 m3/ha in 2020, where the highest applied water value was applied under 120% ETo and the lowest value for 80% ETo. The results also indicated that the values the applied water were higher in first season, compared to the second season, which can also be attributed to the differences in climatic elements. It worth noting that the applied irrigation water was the same for the varieties under biochar treatments. Amer et al. (2019) indicated that the applied irrigation water to spearmint under 120% ETo in clay soil under surface irrigation was 13200 m3/ha.

Water use efficiency (WUE)

The results in Table 7 indicated that the highest WUE were obtained under irrigation with I2 and application of B2 in growing seasons, namely 3.10 and 2.62 kg/m3 in the first season for V1 and V2, respectively. In the second season,it were 3.48 and 2.88 kg/m3 for the same respective varieties. The lowest value of WUE was obtained under irrigation I3, and application of B1. Furthermore, within the irrigation with I3, the highest WUE values were obtained under application of B2.

Water productivity (WP)

The highest WP in both growing seasons were obtained under irrigation with I2 and application of B2 in both seasons, namely 2.63 and 2.23 kg/m3 in the first season for V1 and V2, respectively. In the second seasons, it were 2.96 and 2.45 kg/m3 for the same respective cultivars. The lowest value of WP was obtained under irrigation I3 and B1 (Table 8).

DISCUSSION

Egypt have been already in the era of water scarcity, where it will reach absolute water scarcity (500 m3/capita/year), with population predictions in 2025. Therefore, there is a necessity to find innovations to efficiently manage irrigation water. In the present study, we tested the effects of the interaction between the effects of irrigation amounts and biochar particle size on the yield of two mint varieties and its efficiency in water utilization. The results showed that the highest yield and its attributes resulted from application of 120% ETo and coarse biochar particle size >13 mm. These results can be explained by the SEM images biochar presented in Figure 2, where the macro pores of coarse biochar size have spread across biochar surface and it most active in water absorption, which increase the retention of plant available water (Figure 5B). In addition, application of 120% ETo could have leach the fine biochar particle, which offset the its positive effects and showed the only effect of the coarse biochar particle.

The results also showed that the highest values of water use efficiency and water productivity were obtained under irrigation with 100% ETo and application of fine biochar particle < 1 mm (Figure 5A). This could be attributed to fine particle in biochar slightly increasing of plant available water storage capacity under lower irrigation water, i.e. 100% ETo and it may by more easily to interact with soil particles to form aggregates larger than biochar particles.

These hypothesis of the above mechanisms were confirmed by the findings of Liu et al., (2017), where they indicated that the application of biochar to sand improved the initial water content and its field capacity. They also indicated that adding biochar with high intra-porosity and an irregular shape will be most effective for increasing the plant available water in sandy soils. In addition, they proved that small particle size biochar showed enhanced water retention capacity, and sieved biochar showed 91%–258% larger capacity in water retention than ground biochar of similar particle size, likely because sieved particles were more elongated than ground particles, and thus increased soil inter pore volume. Another theory was defined by Trifunovic et al. (2018), where they indicated that small particle size biochar shows higher water retention content than larger particle size biochar. Similarly, other results reported recently by Trifunovic et al. (2018), for other mechanisms likely to contribute to this effect. First, smaller-sized biochar can easily fill the voids between larger biochar particles and between soil particles, thereby mechanically obstructing the existing pores in the soils. This will increase the tortuosity of water flow in the soils and reduce soil hydraulic conductivity (Lim et al., 2017). Furthermore, as smaller-sized biochar fill the inter-pores between particles, more water can be retained on the surface of the biochar and the soil particles under capillary pressure (Trifunovic et al., 2018). The smaller-sized biochar we used in this investigation were finer than sand particles; therefore, the biochar mechanically blocked water flow in the soil and held water on the biochar surface. Second, biochar with smaller particle sizes likely have more broken intrinsic macro pores, which increases the amount of water that can be stored (Trifunovic et al., 2018). Third, smaller-sized biochar particles generally have higher surface areas and external surface areas (Jaafar et al., 2015), which may directly enhance water retention capacity by increasing cohesion and adhesion between water molecules and the biochar (Mollinedo et al., 2015). Finally, smaller biochar particles can potentially increase soil aggregation by binding the individual soil particles together, which reduces hydraulic conductivity (Ouyang et al., 2013).

CONCLUSION

It could be recommend that, under abundance of irrigation water, to apply irrigation with 120% ETo and application of coarse size biochar particles to spearmint variety to attained higher mint yield. However, under water deficiency, irrigation with 100% ETo and application of fine size biochar particles < 1 mm to spearmint variety is more beneficial to increase water use efficiency and water productivity. These results hold true in sandy soil of El-Behira governorate under drip system.

REFERENCES

Abdelraouf R.E., Essay E.F. and Saleh M.M.S. (2017). Sustainable management of deficit irrigation in sandy soils by producing biochar and adding it as a soil amendment. Middle East Journal of Agriculture Research, 6:1359-1375.

Ali M.E.M. (2018). Effect of Plant Residues Derived Biochar on Fertility of a new Reclaimed Sandy Soil and Growth of Wheat (Triticum aestivum L.). Egypt. J. Soil Sci., 58: 93–103.

Amer A., Abdallah M. and Noreldin T. (2019). Enhancing spearmint productivity and water use efficiency under alternative planting practices. Journal of Central European Agriculture, 20: 852-865.

Arafa A.M.S., Sarhan A.M.Z., Mohamed M.A. and Abd Rabbu H.S. (2017). Effect of Organic Manures with Biofertilizers on Growth and Volatile Oil Production of Mentha longifolia Plant. Middle East Journal of Agriculture Research, 6: 748-756.

Blanco-Canqui H. (2017). Biochar and Soil Physical Properties. Soil Sci. Soc. Am. J., 84: 687

Dai Z. ,Zhang X., Tang C., Muhammad N., Wu, J., Brookes P.C., Xu, J. (2017). Potential role of biochars in decreasing soil acidification-a critical review. Science of the Total Environment, 581: 601-611.

Githinji L. (2013). Effect of biochar application rate on soil physical and hydraulic properties of a sandy loam. Archives of Agronomy and Soil Science, 1–14.

Glaser B. and Birk J.J. (2012). State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de Indio). Geochim. Cosmochim. Acta, 82: 39–51.

Glaser B., Lehmann J., Zech W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal—a review. Biology and Fertility of Soils, 35: 219–230.

Gomez K.A. and Gomez A.A. (1984). Statistics for Agriculture Research. 2nd Ed. John Willey and sons, New York, USA.

Guenther E. (1961). “The Essential Oil “. 4th ed., vol. III.D. Van. Nostrand company, Inc., New York.

Herath H.M.S.K., Camps-Arbestain M., Hedley M. (2013). Effect of biochar on soil physical properties in two contrasting soils: An Alfisol and an Andisol. Geoderma, 209–210:188–97.

Ibrahim M., Mahmoud E., Gad L. and Khader A. (2019). Effects of biochar and phosphorus fertilizer rates on soil physical properties and wheat yield on clay textured soil in middle Nile Delta of Egypt. Communications in Soil Science and Plant Analysis, 50: 2756-2766.

Jaafar N.M., Clode P.L., Abbott L.K. (2015). Soil microbial responses to biochars varying in particle size, surface and pore properties. Pedosphere, 25: 770–780.

Karhu K., Mattila T., Bergstrom, I. and Regina K. (2011). Biochar addition to agricultural soil increased CH4 uptake and water holding capacity – Results from a short-term pilot field study. Agr. Ecosyst. Environ., 140: 309–313.

Kashyap S. and SharmaS. (2005). Role of bioinoculants and auxin in development of salt tolerant Mentha arvensis. Hort. Sci. (Prague), 32: 31-41.

Khalifa D.M. and Elareny I.M. (2020). Effect of Olive mill Wastewater and Biochar under Different NPK Rates on Sandy Soil Properties and Peanut productivity. Middle East Journal of Agriculture Research, 9: 624-635.

Lehmann, J. and Joseph, S. (2009). Biochar for environmental management: science and technology. Earthscan, Oxford, UK.

Lim, T.J., Spokas, K.A., Feyereisen, G.W., Weis, R., Koskinen, W.C. (2017). Influence of biochar particle size and shape on soil hydraulic properties. J. Environ. Sci. Eng., 5:8–15.

Liu Z., Dugan B., Masiello C.A., Gonnermann H.M. (2017). Biochar particle size, shape, and porosity act together to influence soil water properties. PLoS ONE 12, e0179079.

Mohamed I., El-Meihy R., Ali M., Chen F. and Raleve D. (2017). Interactive effects of biochar and micronutrients on faba bean growth, symbiotic performance, and soil properties, Journal of Plant Nutrition and Soil Science 180: 729-738.

Mollinedo J., Schumacher T.E., Chintala R. (2015). Influence of feedstocks and pyrolysis on biochar’s capacity to modify soil water retention characteristics. J. Anal. Appl. Pyrolysis, 114:100–108.

Mustafa A.Z., Badr A., El-Galaly Mobarak A.A. (2005). Hassan MG. Genetic diversity among Mentha populations in Egypt as reflected by isozyme polymorphism. Int. J. Bot., 1: 188-195.

Ouyang, L., F. Wang, J. Tang, L. Yu, and R. Zhang (2013). Effect of biochar amendment on soil aggregates and hydraulic properties. J. of Soil Sci. and Plant Nutr., 13: 991- 1002.

Page A.L., Miller R.H., and Keeney D.R. (1982). Methods of soil analysis. II Chemical and Microbiological properties 2nd Ed. Madison, Wisconsim. U.S.A.

Sadowska U., Domagała-Swiatkiewicz I. and Zabi´nskiA.j. (2020). Biochar and Its Effects on Plant–Soil Macronutrient Cycling during a Three-Year Field Trial on Sandy Soil with Peppermint (Mentha piperita L.). Part I: Yield and Macro Element Content in Soil and Plant Biomass. Agronomy, 10:1950.

Sarong M. and Orge R.F. (2015). Effect of rice hull biochar on the fertility and nutrient holding capacity of sandy soils. OIDA International Journal of Sustainable Development: 8: 33-44.

Scora R.W. and Chang A.C. (1997). Essential oil quality and heavy metal concentrations of peppermint grown on a municipal sludge-amended soil. J. Environ. Qual., 26: 975-979.

Snyder R.L., Orang M., Bali K. and Eching S. (2004). Basic irrigation scheduling BIS. http://www.waterplan.water.ca.gov/landwateruse/wateruse/Ag/CUP/Californi/Climate_Data_010804.xls

Stackman W.P. (1966). Determination of pore Size by the air bubbling pressure method. Proceeding unesco Symp on water in the unsaturated zone, 366- 372.

Stanhill G. (1986). Water use efficiency. Advances in Agronomy, 39: 53-85.

Tan K.H. (1996). Soil Sampling, Preparation and Analysis. Marcel Dekker, Inc. New York, p. 391.

Trifunovic B., Gonzales H.B., Ravi S., Sharratt B.S., Mohanty S.K. (2018). Dynamic effects of biochar concentration and particle size on hydraulic properties of sand. Land Degrad. Dev., 29: 884–893.

Vermeiren L. and Jopling G.A. (1984). Localized irrigation. FAO Irrigation and Drainage paper No. 36, Rome, Italy.

Veronese P., Li X., Niu X., Weller S.C., Bressan R.A. and Hasegawa P.M. (2001). Bioengineering mint crop improvement. Plant Cell Tissue Organ Cult., 64: 133-144.

Waller R.A. and Duncan D. B. (1969). A Bayes rule for the symmetric multiple comparisons problem. J. Amer. Statist. Ass., 64: 1484–1503.

Wang B., Gao B., Zimmerman A.R., Zheng Y., Lyu H. (2018). Novel biochar-impregnated calcium alginate beads with improved water holding and nutrient retention properties. J. Environ. Manag., 209: 105–111.

Zhang (2003). Compound decision theory and empirical Bayes methods. Invited paper. The Annals of Statistics, 31: 379-390.

References