Egypt. J. Hort. **Vol. 45,** No. 1, pp. 169-183 (2018)

Amending Sandy Soil with Biochar or/and Superabsorbent Polymer Mitigates the Adverse Effects of Drought Stress on Green Pea

G. S. Riad*, S. M. Youssef, Nashwa A.I. Abu El-Azm** and Enas M. Ahmed*****
** Vegetable Research Department, National Research Centre, Dokki, 12622 Cairo, Egypt ** Department of Horticulture, Faculty of Agriculture, Ain Shams University, Shubra Al Khaymah 11241 Cairo, Egypt and*** Chemical Engineering and Pilot Plant Department, National Research Centre, Dokki, 12622 Cairo, Egypt.*

FACED with the scarceness of water resources and climate changes, drought is undoubtedly one of the most important abiotic stresses limiting the growth and productivity of plants including green pea, especially in the arid and semi-arid areas. The uses of soil amendments like biochar and superabsorbent polymer, which characterized by enhancing water holding capacity and improving soil physical properties, become more important in these areas. A lysimeter experiment with sandy soil in a completely randomized design was carried out in three replicates to study the effect of biochar or/and superabsorbent polymer on the growth and productivity of green pea (*Pisum sativum* L.) cv. Master B under full irrigation (100% of water requirement) and water deficit regime (75% of water requirement) conditions during 2015/2016 and 2016/2017 seasons at the Experimental Research Farm of the Horticulture Department, Faculty of Agriculture, Ain Shams University, Qalyubia Governorate, Egypt. Results revealed that lowering irrigation level to 75% of water requirements led to significant decreases in vegetative growth parameters, SPAD readings, leaf relative water content, leaf nutrients (N, P, and K) and pod yield components compared with the full irrigation. Adding biochar or/and superabsorbent polymer significantly increased the aforementioned characters under both full irrigation and water deficit conditions. Application of biochar with superabsorbent polymer was the most efficient treatment to alleviate the deleterious effects of water deficit on green pea cultivation in sandy soils. In conclusion, applying biochar (1% w/w) with superabsorbent polymer (0.7% w/w) might be a promising novel approach to improve sandy soils characteristics and help green pea cultivation in these soils which are characterized by a low water holding capacity and low fertility.

Keywords: *Pisum sativum*, Soil amendments, Hydrogel, Water deficit, Leaf relative water content, Water holding capacity.

Introduction

Green pea (*Pisum sativum* L.) is one of the main leguminous vegetables grown during the winter season in Egypt for local markets and exportation. In Egypt, green pea production area was 18471 ha with a total production of 184018 tonnes and an average yield of 9.96 tonnes ha^{-1} (FAOSTAT, 2014). Large parts of the Egyptian agricultural land are located in arid or semi-arid regions where water is becoming scarcer and more costly. Faced with the scarceness of water resources in those areas, drought is undoubtedly one of the most dangerous abiotic stresses limiting the growth and productivity of plants around the world including green pea (Sorensen et al., 2003, Farooq et al., 2012, Rezaei et al., 2014, Bodah et al., 2015 and Osman, 2015). The uses of soil amendments like biochar and the superabsorbent polymer which characterized by water holding amendments and improving soil physical properties will become more important over time, especially in the regions of water scarcity such as most Middle East and African countries.

Biochar, or charcoal, is produced from a thermal decomposition of organic material in the absence of oxygen or under low oxygen availability at temperatures above 700°C (Lehmann and Joseph, 2015). The usage of biochar as a soil amendment

Corresponding author: sabrysoliman@hotmail.com, sabry_youssif@agr.asu.edu.eg,
DOI: 10.21608/EJOH.2018.3860.1067

is dated back to the pre-Columbian Indios who built up the nutrient-rich "Terra Preta", or black soil, by adding large quantities of charcoal to the soils (Glaser et al., 2002). Moreover, the production of biochar from the crop residues may enhance soil fertility on one hand and on the other hand may act as an eco-sustainable management approach for recycling the organic materials and reduce CO_2 emissions (Akhtar et al., 2014). Biochars are rich in organic carbon concentration (30 to 70%), and characterized with high mineral contents, high values of pH and EC, and a low concentration of ash (Batool et al., 2015, Qayyum et al., 2015). Applications of biochar have recently received a significant attention due to the improving the soil physicochemical properties and enhancing the soil fertility including cation exchange capacity, soil pH, water holding capacity, water and fertilizer use efficiency, soil microbial interactions, and immobilization of both organic and inorganic pollutants under normal and abiotic-stress conditions (Abel et al., 2013, Beesley and Marmiroli, 2011, Fiaz et al., 2014, Hammer et al., 2015, Lehmann and Joseph, 2015, Ok et al., 2015, Bamminger et al., 2016, Inyang et al., 2016 and Abbas et al., 2017). Along with improved the soil fertility, biochar application on plant growth, photosynthesis, nutrient uptake, and yield have been widely reported under water deficit conditions (Akhtar et al., 2014, Batool et al., 2015, Afshar et al., 2016, Kim et al., 2016, Egamberdieva et al., 2017 and Liu et al., 2017). Application of biochar has been reported to enhance the growth and productivity of some vegetable crops such as tomato (Akhtar et al., 2014), okra (Batool et al., 2015), and cucumber (Nadeem et al., 2017) under reduced irrigation. Furthermore, biochar can potentially enhance plant resistance against various aerial and soil-borne pathogens (Bonanomi et al., 2015), with evidences that disease severity is biochar dose-dependent (Jaiswal et al., 2015).

Superabsorbent hydrogels are loosely cross-linked of flexible polymers with few numbers of widthwise links, making them capable of absorbing and storing water hundreds of times of their dry weight (Abedi-Koupai and Asadkazemi, 2006, Kiatkamjornwong, 2007). Their performances are determined by the chemical properties of the hydrogel such as structure, molecular weight and formation conditions of the hydrogel. They can be applied in agriculture to improve the physical properties of soil (Orzeszyna et al., 2006), increase the water-holding capacity of soil (Akhter et al., 2004, Sarvaš et al., 2007, Yang et al., 2014 and Ahmed et al., 2015a), release water slowly through soil (Orzeszyna et al., 2006, Khadem et al., 2010), reduce the waste of water and prevent leaching of nutrients from soils (Kim et al., 2010), reduce the soil water evaporation (Akhter et al., 2004 and Sarvaš et al., 2007), causing the better growth of plants and consequently increasing crop yield under normal irrigation and drought stress conditions. Thus, superabsorbent polymers may provide an excellent solution for plants grown in newly-reclaimed land in sandy soils and for the plants that may suffer even partially from drought stress. In this respect, application of superabsorbent polymers has been demonstrated to attenuate the hazardous effects of drought in some legumes such as soybean (Yazdani et al., 2007), red bean (Pouresmaeil et al., 2012a, 2012b, 2013), mung bean (Mehraban and Afrazeh, 2014), and snap bean (Ahmed et al., 2015b). In addition, application of superabsorbent polymers has been reported to alleviate the deleterious effects of drought in some vegetable crops such as tomato (Kamal and El-Shazly, 2013, Shahrokhian et al., 2013, Fernando et al., 2014, El Sagan, 2015), lettuce (Beig et al., 2014), squash (El-Tohamy et al., 2014), and pumpkin (Safavi et al., 2016).

In recent years, there is a growing interest in improving of water holding capacity of the soils and water use efficiency to face the water deficit using different soil amendments. Therefore, this study was designed to assess the impact of biochar or/and superabsorbent hydrogel on the growth and productivity of green pea (*Pisum sativum* L.) cv. Master B under full irrigation (100% of water requirement) and water deficit (75% of water requirement) conditions.

Materials and Methods

Plant Material and Experimental Site

A lysimeter experiment was conducted to evaluate the effect of biochar or/and superabsorbent polymer on the growth and productivity of green pea (*Pisum sativum* L.) cv. Master B under full irrigation (100% of water requirement; 3500 m^3 ha^{-1} as reported by the Arab Organization for Agricultural Development) and drought stress (75% of water requirement) conditions during 2015/2016 and 2016/2017 seasons at the Experimental Research Farm of the Horticulture Department, Faculty of Agriculture, Ain Shams University, Qalyubia Governorate, Egypt (30º06′46″N, 31º14′37″E).

Treatments and Growth Conditions

Four treatments of soil amendments, i.e. no amendment (as control), biochar, superabsorbent polymer, and biochar with superabsorbent polymer were evaluated under two levels of irrigations (100 or 75% of water requirement) in green pea under sandy soil conditions.

The biochar used in the experiment was produced from orange wood waste by pyrolysis at 450º C using reactor according to the procedure described by Odesola and Owoseni (2010). It was ground into a fine powder. The chemical analysis of the used biochar is presented in Table 1.

ACMC-g- poly (AAc– co- AAM) superabsorbent hydrogel was obtained from Chemical Engineering and Pilot Plant Department, National Research Centre, Egypt. Carboxymethyl cellulose sodium (CMC) powder was dissolved in distilled water and heated to 80ºC to prepare CMC solution. Potassium persulfate was added and kept at 80ºC for 10 min to generate radicals. After cooling to 40ºC, the mixture of acrylic acid, acrylamide monomers and N,N-methylenebisacrylamide was added, and then pH was adjusted. The temperature was levitated to 80ºC and maintained for 2 h to accomplish the reaction. The obtained product was washed using methanol/water, dried, weighed, ground, and packed. The super absorbent hydrogel produced is characterized by high swellability (190 g/g) and best cohesive properties.

TABLE 1 Chemical analysis of orange-wood biochar.

pH_w (1:2 w:v)	C (%)	N (%)	H (%)	O (%)	PO_4-P (%)	K (%)	S (ppm)	Fe (ppm)	CEC† (cmol g^{-1})	Acidity	WHC‡ (g g^{-1})
7.3	84.9	0.79	2.19	9.6	0.06	0.92	140	520	15.3	0.59	4.3

†Cation exchange capacity ‡ Water holding capacity

The biochar and superabsorbent polymer were applied to the soil at a rate of 1 and 0.7% by weight, respectively. These rates of both biochar and superabsorbent polymer application were based on the previous studies (El-Tohamy et al., 2014, Ahmed et al., 2015b, Batool et al., 2015). The amounts of biochar or/and superabsorbent polymer incorporated were calculated on the 30 cm depth. These quantities were thoroughly mixed into the upper 30 cm of the soil using a mechanical tiller prior to planting.

Green pea (*Pisum sativum* L.) cv. Master B seeds were sown in 1 x 2 x 1 m (W x L x H) lysimeters containing washed sand on 4th November and 3rd November, respectively in both growing seasons. Each lysimeter area was 2 m^2 included ten rows; each one was 1 X 0.2 m. The plant distance was 10 cm apart in the row. After seedling emergence, the experimental lysimeters were subjected to two irrigation regimes, i.e. full irrigation (100 of water requirement) or deficit irrigation (75% of water requirement). The amounts of irrigation water at both regimes were calculated and added according to growth stage of green pea plants during the growing season.

In both seasons, the recommended agricultural practices were used for the green pea production under sandy soils conditions, i.e. irrigation, fertilization and diseases and pest control were followed according to the Egyptian Ministry of Agriculture.

Data Recorded

Vegetative growth parameters

A random sample of ten plants/ replicate was collected at 40 days after sowing to assess the growth characteristics. The lengths of root and plant were measured using a meter scale and number of leaves per plant was counted.

The plants were carefully shoveled out of the soil, to prevent damage to the root system, and then the excess soil around the roots was carefully removed. The plants were carried to the laboratory where the roots were washed to remove the rest of attached soil. Fresh weights of root and vegetative growth were recorded and then dried at 70°C until constant weight to record the dry weights.

SPAD readings

A portable chlorophyll meter (SPAD–502, Konica Minolta Sensing, Inc., Japan) was used to measure the leaf greenness. At 40 days after sowing, the measurements were taken on the second topmost fully expanded leaves of randomly selected five plants per lysimeter (replicate) and then averaged.

Leaf relative water content

Leaf relative water content (LRWC) was determined according to the Barrs and Weatherley (1962). Twenty leaflets of fully expanded leaves were used for determining relative water content. Fresh weight (FW) was immediately recorded, and then the leaflets were immediately immersed for 4 hours in distilled water at room temperature under a constant light and saturated humidity. The leaflets were taken from the away distilled water and were carefully dried with tissue paper to record fully turgid weight (TW). The leaflets were then dried for 24 hours at 80 ºC for recording dry weight (DW). Relative water content (RWC) was calculated by the following formula:

$$RWC\ (\%) = \frac{(FW\text{-}DW)}{(TW\text{-}DW)} \times 100$$

Analysis of leaf nitrogen, phosphorus and potassium

For analysis of nitrogen, phosphorus, and potassium, leaf samples were gathered at 40 days after sowing and oven-dried at 70 °C until constant weight. Then finely grounded dry leaf samples (100 mg) were taken and wet digested using sulphuric acid (H_2SO_4 98 %) and hydrogen peroxide (H_2O_2 30 %) as described by Thomas et al. (1967). All the studied nutrients were assayed in the digested solution of the concerned plant samples. Nitrogen content was assessed using the Kjeldahl method (Piper, 1950). Phosphorus content was estimated by ascorbic acid method (AOAC, 2016). Potassium content was quantified according to Chapman and Pratt (1961).

Yield of green pods

The green marketable pods of each lysimeter were harvested during the growing season, counted, and weighed to record number of pods/ plant, and pod yield.

Experimental Design and Statistical Analysis

A completely randomized design with three replicates was performed. All data were homogeneous and normal distributed and then subjected to an analysis of variance using the CoStat package program (Version 6.303; CoHort Software, USA). The differences among the means were compared using the least significance difference (LSD) at $P \leq 0.05$. These data were then plotted using SigmaPlot (Version 11.0; Systat Software, Inc. SigmaPlot for Windows) to create a vertical bar chart.

Results and Discussion

Vegetative Growth Parameters

In both growing seasons, data in Fig. 1 and 2 clearly show that decreasing the water requirements to 75% led to pronounced decreases in plant growth parameters and biomass accumulation, i.e. root length, plant length, number of leaves/ plant, and fresh and dry weights of roots and vegetative growth of green pea plants as compared with 100% WR. Similar reductions in plant growth parameters of pea plants were reported under drought stress (Bodah et al., 2015, Osman, 2015). These reductions in growth parameters resulting from reducing water requirements could be attributed to the impairing effects of drought on cell division, cell enlargement, and cell differentiation processes (Taiz et al., 2015), the lower rates of water and nutrients absorption and translocation (Farooq et al., 2009), the partial/full closure of stomata to conserve water resource and prevent the transpirational water loss (Osakabe et al., 2014, Tardieu et al., 2014), decreases in chlorophyll content and lower photosynthetic rates (Farooq et al., 2009), increases in abscisic acid content (Dodd, 2007), and reductions in enzyme activities (Moran et al., 1994, Osman, 2015). In addition, stomatal closure decreases the inflow of CO_2 into the leaves and releases more electrons for the generation of reactive oxygen species (ROS) which negatively affected plant growth.

Applications of biochar or/and superabsorbent polymer significantly increased all vegetative growth parameters of pea plants compared with the untreated plants in both full irrigation and water deficit conditions. Except for the root length in the second season, adding superabsorbent polymer or superabsorbent polymer with biochar gave the highest significant values of these parameters. Adding biochar with superabsorbent polymer gave the highest significant values of these parameters in both seasons (Fig. 1 and 2). Application of biochar has a pronounced enhancement in vegetative growth parameters of some vegetable crops such as tomato (Akhtar et al., 2014), okra (Batool et al., 2015), potato (Liu et al., 2017) and cucumber (Nadeem et al., 2017) under reduced irrigation. These increments in the growth and biomass accumulation are probably due to the improving the soil physicochemical properties under normal and abiotic-stress conditions (Abel et al., 2013, Hammer et al., 2015, Bamminger et al., 2016, Inyang et al., 2016). Biochar application also enhanced soil fertility, water use efficiency, carbon sequestration, and immobilization of soil pollutants (Akhtar et al., 2014, Fiaz et al., 2014, Batool et al., 2015, Ok et al., 2015 and Abbas et al., 2017).

Additionally, some physiological parameters,

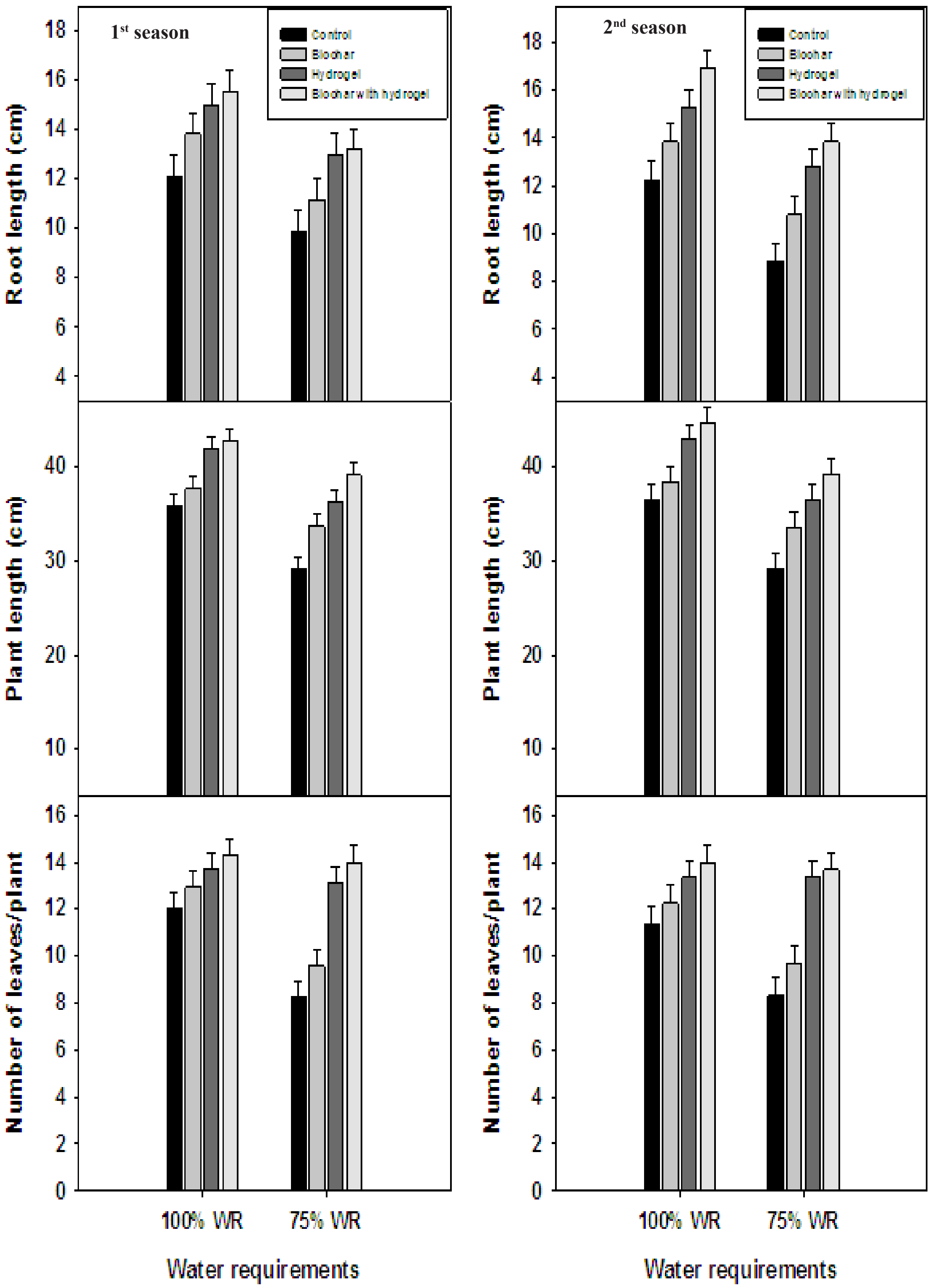

Fig. 1. Effect of biochar or/and superabsorbent hydrogel application on some vegetative growth parameters of green pea (*Pisum sativum* L.) cv. Master B under full irrigation and water deficit conditions during 2015/2016 and 2016/2017 seasons. Vertical bars indicate the LSD value at P ≤ 0.05.

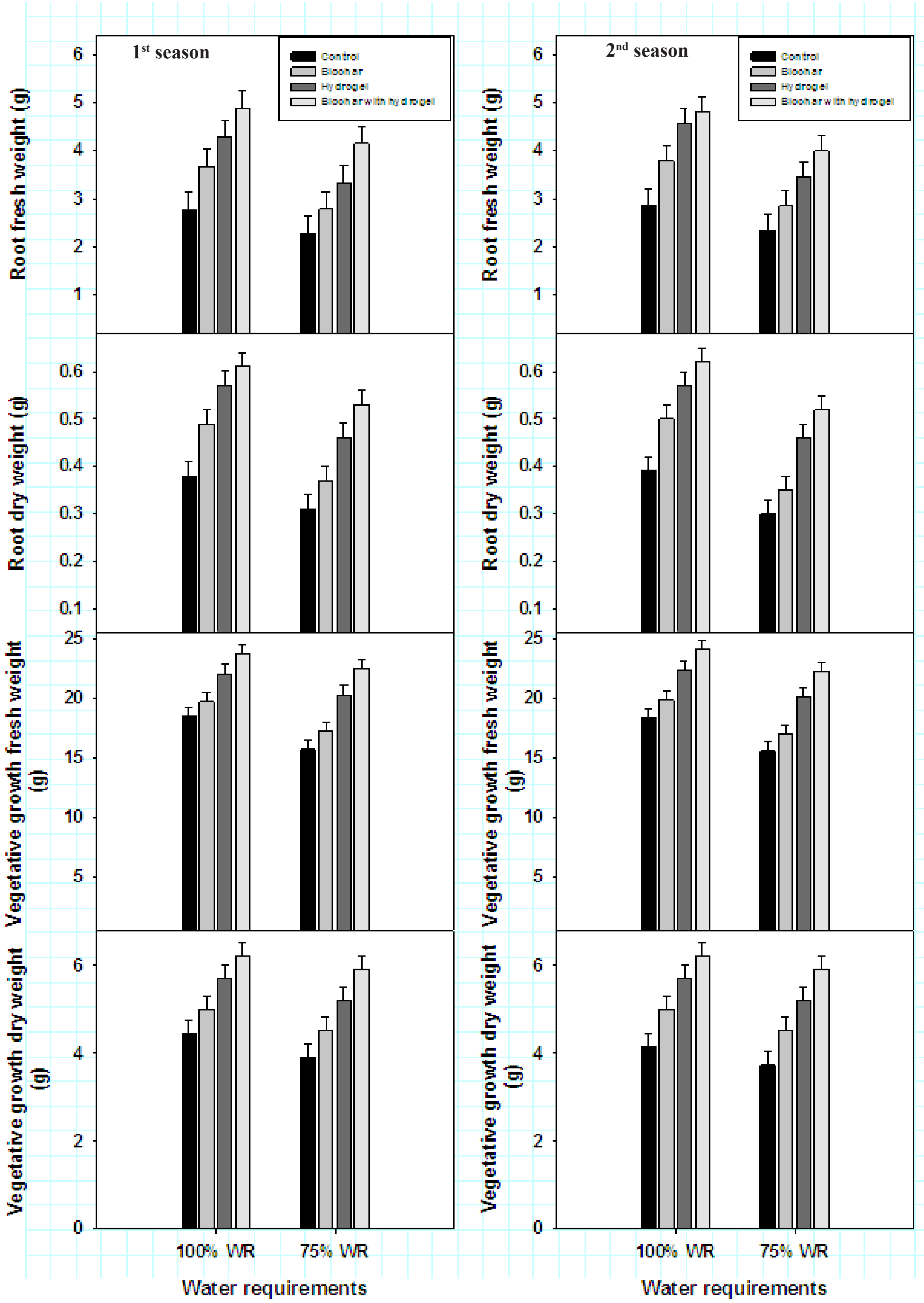

Fig. 2 Effect of biochar or/and superabsorbent hydrogel application on fresh and dry weights of roots and vegetative growth of green pea (*Pisum sativum* L.) cv. Master B under full irrigation and water deficit conditions during 2015/2016 and 2016/2017 seasons. Vertical bars indicate the LSD value at P ≤ 0.05.

i.e. stomatal conductance, leaf relative water content and leaf membrane stability (Akhtar et al., 2014) were enhanced after biochar application under water deficit conditions, which consequently causing enhancements in plant growth parameters. Similarly, earlier studies indicated that application of superabsorbent polymer stimulated the vegetative growth of tomato (Kamal and El-Shazly, 2013, Shahrokhian et al., 2013, Fernando et al., 2014 and El Sagan, 2015), lettuce (Beig et al., 2014), squash (El-Tohamy et al., 2014), and snap bean (Ahmed et al., 2015b) under reduced irrigation level. Superabsorbent polymer application improved the physical properties of soil (Orzeszyna et al., 2006), increased the hydraulic conductivity of soil (El-Tohamy et al., 2014), increased the water-holding capacity of soil (Akhter et al., 2004, Sarvaš et al., 2007, Shahrokhian et al., 2013, Yang et al., 2014 and Ahmed et al., 2015a), released water slowly through soil (Orzeszyna et al., 2006, Khadem et al., 2010), reduced the waste of water and prevented leaching of nutrients from soils and subsequently increased water and fertilizer use efficiency (Kim et al., 2010, Kamal and El-Shazly, 2013, Shahrokhian et al., 2013 and El-Sagan, 2015), reduced the soil water evaporation (Akhter et al., 2004 and Sarvaš et al., 2007), causing the better growth of plants under normal irrigation and drought stress conditions. In the current study, it was found that superabsorbent polymer application attenuated the detrimental effects of water deficit more than biochar application and this may be attributed to its superior ability to retain more water. In addition, the highest values of pea growth obtained from adding biochar with superabsorbent polymer together may be resulted from the synergistic effects between both soil amendments.

SPAD Readings of Leaves

Under water deficit, the SPAD readings of pea leaves were diminished compared with the plants grown under full irrigation (Fig. 3). Under water stress, similar reductions in chlorophyll contents in pea leaves were reported (Moran et al., 1994, Shinde and Thakur, 2015). The decreases in chlorophyll content, expressed by SPAD readings in this study, under drought stress have been considered a typical symptom of oxidative stress and may be the result of pigment photo-oxidation and chlorophyll degradation (Herbinger et al., 2002). The decreases in chlorophyll content are accompanied with decreases in the photosynthetic rate, resulting in less assimilate production for plant growth. In this concern, the reductions of SPAD readings under water deficit (Fig. 3) are in good accordance with the reductions of plant growth parameters (Figs. 1 and 2).

These readings were significantly increased with adding biochar or/and superabsorbent polymer under both full irrigation and water deficit. Applications of superabsorbent polymer with or without biochar gave the highest significant readings (Fig. 3). Previous studies have reported that the biochar application improved chlorophyll contents and the photosynthesis of drought-stressed tomato (Akhtar et al., 2014), and okra (Batool et al., 2015). Also, application of superabsorbent polymer increased chlorophyll content in leaves of tomato (Kamal and El-Shazly, 2013), and snap bean (Ahmed et al., 2015b). The increments in chlorophyll content with the application of both amendments might be ascribed to their properties of nutrient retention, among them iron and magnesium which are considered

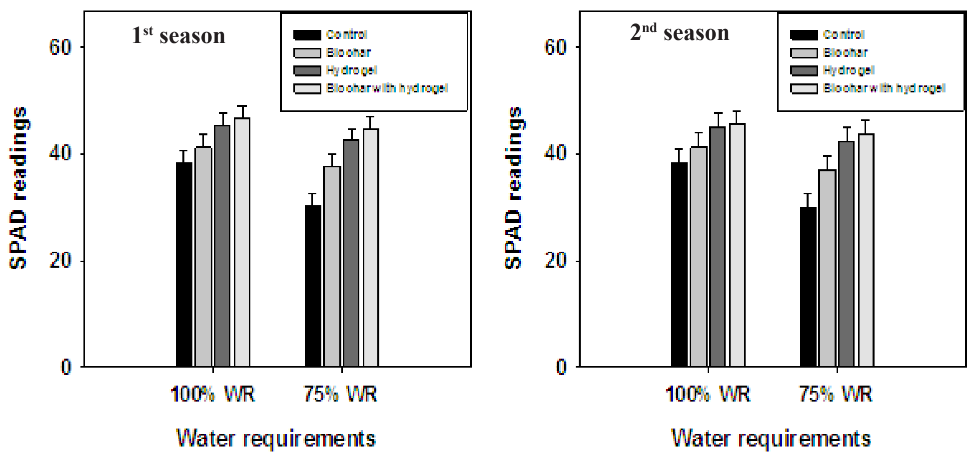

Fig. 3. Effect of biochar or/and superabsorbent hydrogel application on SPAD readings of green pea (*Pisum sativum* L.) cv. Master B under full irrigation and water deficit conditions during 2015/2016 and 2016/2017 seasons. Vertical bars indicate the LSD value at P ≤ 0.05.

as the two important nutrients involved in chlorophyll synthesis.

Leaf Relative Water Content

It is obvious from Fig. 4 that water-stressed pea plants had lower relative water content than non-stressed ones in both growing seasons. Similar reductions in relative water content were reported in pea leaves (Moran et al., 1994, Jovanović et al., 2013) under drought stress. It is well known that under water deficit, the absorption and translocation of water and nutrients are reduced. This reduction in water absorption induced by drought stress may cause a lowering in the relative water content of leaves which would result in the partial/full closure of stomata to maintain their water status and transpiration decrease. In addition, Farooq et al. (2009) found that the activities of the photosynthetic enzymes; i.e. phosphoenolpyruvate carboxylase, rubisco, fructose-1, 6-bisphosphatase, and pyruvate orthophosphate dikinase decreased linearly with lowered leaf water potential under drought stress. In this connection, the reductions of SPAD readings under water deficit (Fig. 3) coincide with the reductions of leaf relative water content (Fig. 4).

Applications of biochar or/and superabsorbent polymer significantly increased the relative water content under both normal and water-deficit conditions. Similarly, application of biochar significantly improved leaf relative water content of drought-stressed tomato plants (Akhtar et al., 2014). Likewise, applications of superabsorbent polymer increased relative water content in the leaves of squash (El-Tohamy et al., 2014), and tomato (El Sagan, 2015). Adding superabsorbent polymer alone or with biochar gave the highest significant values of relative water content. The enhancement of leaf relative water content in pea plants might be attributed to the water retention properties of both soil amendments. The improvement of plant water status of pea plants could be contributed to the increased plant growth in the biochar- and superabsorbent polymer-treated plants. In this concern, the increments in leaf relative water content (Fig. 4) concur with the increases in plant growth parameters (Fig. 1 and 2) of the plants grown in soils amended with biochar or/and superabsorbent polymer.

Nitrogen, Phosphorus and Potassium Contents of Leaves

Data in Fig. 5 demonstrated that decreasing the water requirements to 75% significantly reduced the accumulation of nitrogen, phosphorus, and potassium in pea leaves in both growing seasons. It is known that diminishing water availability under water deficit conditions generally results in limited uptake of nutrients and reductions in nutrient concentrations in leaf tissues (Farooq et al., 2012). These findings are in accordance with the results of Shinde and Thakur (2015) who found that water stressed plants could exploit a

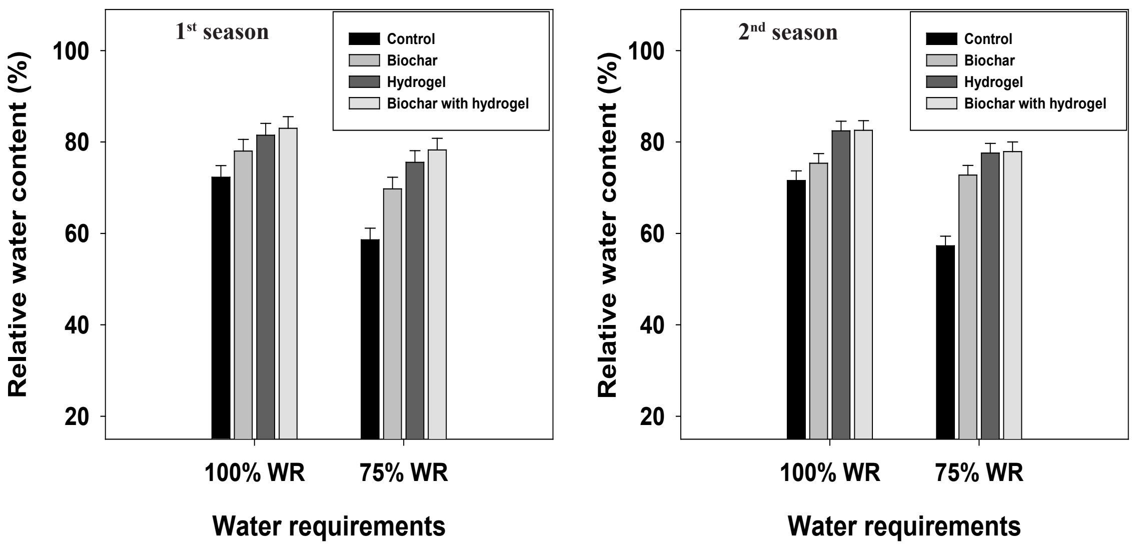

Fig. 4. Effect of biochar or/and superabsorbent hydrogel application on leaf relative water content of green pea (*Pisum sativum* L.) cv. Master B under full irrigation and water deficit conditions during 2015/2016 and 2016/2017 seasons. Vertical bars indicate the LSD value at P ≤ 0.05.

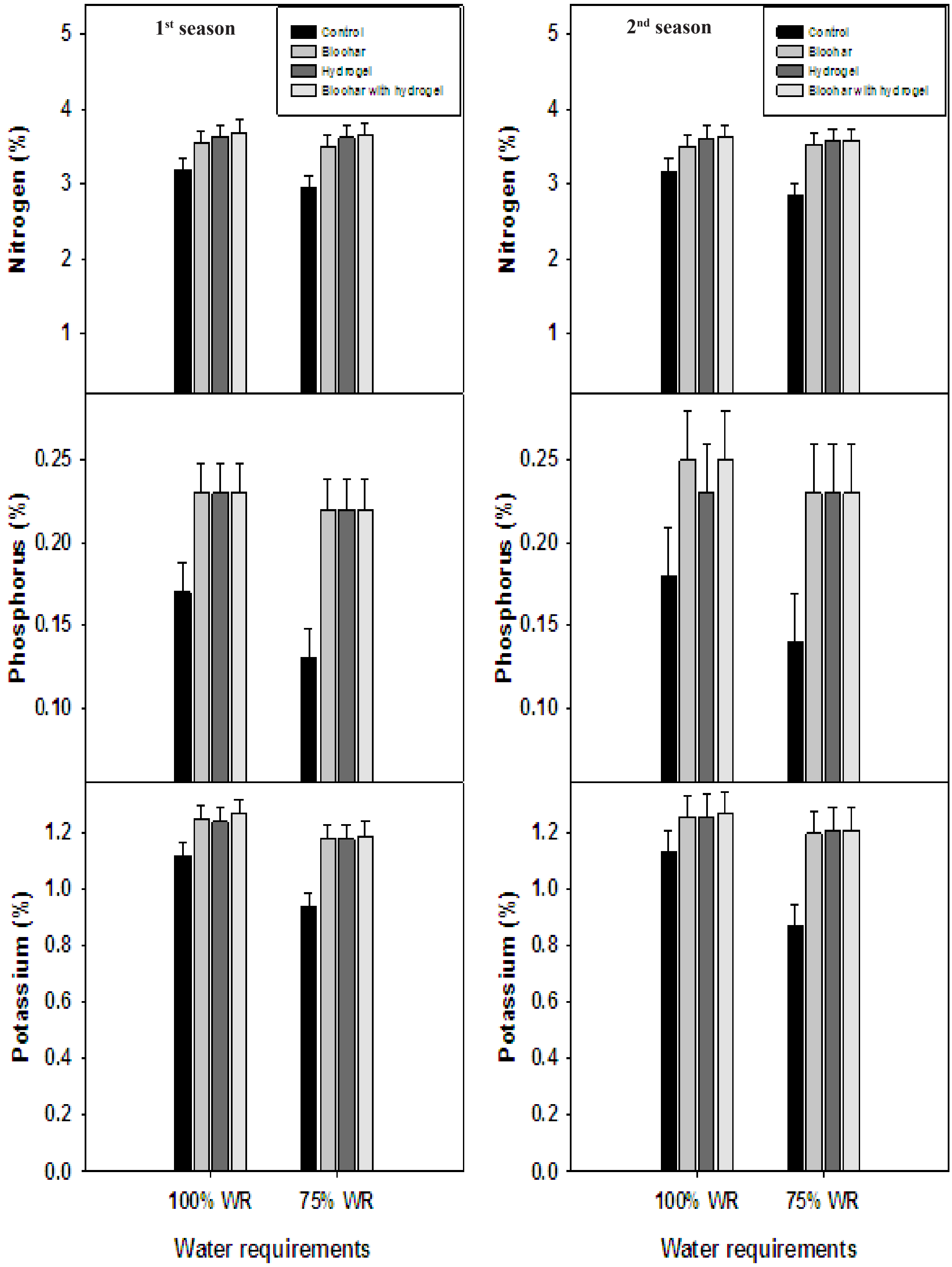

Fig. 5. Effect of biochar or/and superabsorbent hydrogel application on N, P, and K concentrations of leaves of green pea (*Pisum sativum* L.) cv. Master B under full irrigation and water deficit conditions during 2015/2016and 2016/2017 seasons. Vertical bars indicate the LSD value at P ≤ 0.05.

large quantity of carbon and nitrogen resources into the synthesis of osmoregulants, such as proline, in the leaves for maintaining cell turgor.

Under full-irrigation conditions, adding biochar or/and superabsorbent polymer increased significantly the accumulation of these nutrients as compared with the control plants. However, these increments were not significant among the three applications. A similar trend was found under the water-deficit conditions. In this connection, Lehmann et al. (2003) found that higher biochar application significantly increased P, K, Ca, Zn, and Cu uptake by cowpea and rice plants, and reduced the leaching of the applied N fertilizer, while both of Ca and Mg leaching was delayed. Furthermore, similar increases in nutrients accumulation were reported in tomato (Kamal and El-Shazly, 2013, El Sagan, 2015) after superabsorbent polymer application. The improvement of the accumulation of nitrogen, phosphorus, and potassium in pea leaves under water deficit in sandy soils may be due to not only the properties of water and nutrients retention of both used soil amendments which create favorable conditions for nutrients uptake (Kim et al., 2010, Kamal and El-Shazly, 2013, Shahrokhian et al., 2013), but also biochars add some macro- and micro-nutrients to the soils.

Pod Yield

In both growing seasons, lowering the irrigation water to 75% WR decreased the number of pods/ plant and pod yield/plant of green pea (Fig. 6). These reductions were 25.78 and 21.67% for pod yield compared with full irrigation conditions in the first and second season, respectively. Similar reductions in pod yield of pea plants were reported under water drought (Bodah et al., 2015, Osman, 2015).These drought-related reductions could be ascribed to stomatal closure in response to low soil water content, which reduced the intake of CO_2 and consequently photosynthesis diminished (Flexas et al., 2004), reducing plant growth and development, and leading to reductions in dry matter production, assimilate translocation and dry matter portioning (Farooq et al., 2009). In this concern, the reductions of pod yield under water deficit (Fig. 6) are in good accordance with the reductions of nutrients

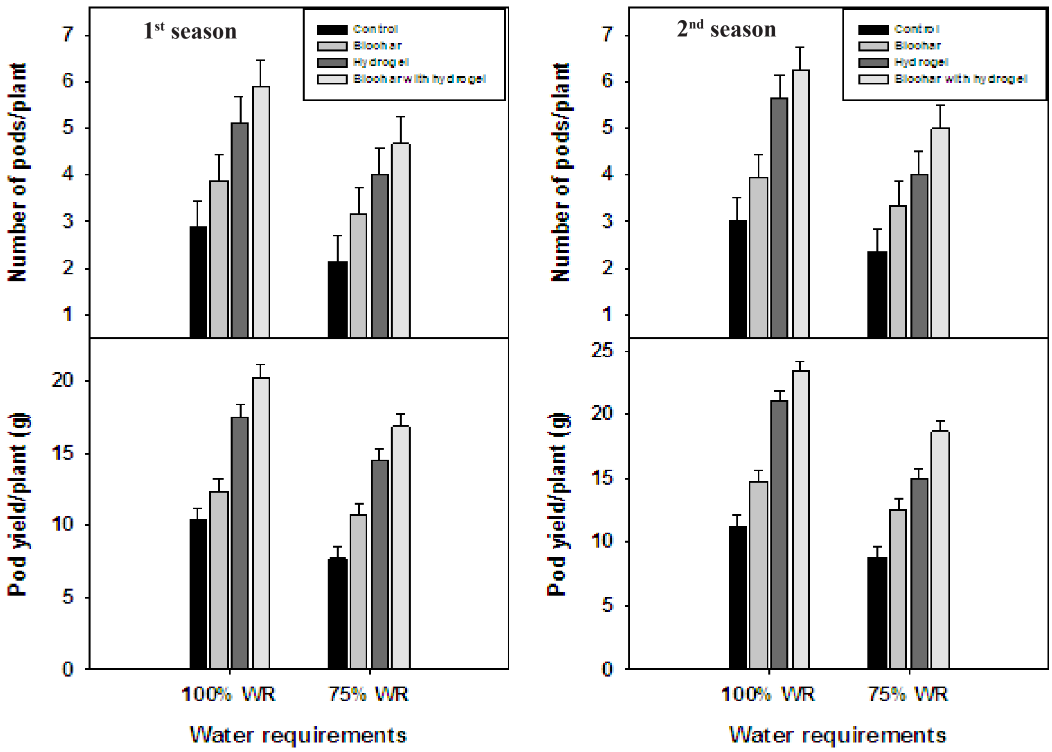

Fig. 6. Effect of biochar or/and superabsorbent hydrogel application on number and yield of pods/plant of green pea (*Pisum sativum* L.) cv. Master B under full irrigation and water deficit conditions during 2015/2016 and 2016/2017 seasons. Vertical bars indicate the LSD value at P ≤ 0.05.

accumulation (Fig. 5), leaf relative water content (Fig. 4), SPAD readings (Fig. 3), and plant growth parameters (Fig. 1 and 2).

Applications of biochar or/and superabsorbent polymer significantly increased the pod number and pod yield compared with the control plants under both 100 and 75% of water requirements. It is noted that application of biochar along with superabsorbent hydrogel doubled pod yield in both full irrigation and water deficit conditions. In this concern, application of biochar has been reported to enhance the productivity of some vegetable crops such as tomato (Akhtar et al., 2014), okra (Batool et al., 2015), and cucumber (Nadeem et al., 2017) under reduced irrigation. Liu et al. (2013) reported the greatest positive influence of biochar on crop productivity when incorporated into acidic, clay, or sandy soils with low water holding capacity or low organic matter. In addition, earlier studies demonstrated that application of superabsorbent polymer increased pod yield of snap bean (Ahmed et al., 2015b), as well as the yield components of some other vegetable crops such as tomato (Kamal & El-Shazly, 2013, Shahrokhian et al., 2013 and El Sagan, 2015), squash (El-Tohamy et al., 2014), and pumpkin (Safavi et al., 2016) under reduced irrigation level. These increases in pod yield of green pea after application of both used amendments (Fig. 6) may be back to their enhancing effects on the vegetative growth parameters (Fig. 1 and 2), leaf relative water content (Fig. 3), chlorophyll content (Fig. 4), and leaf nutrients status (Fig. 5), resulting from improving water holding capacity, along with enhanced nutrient retention of the soil.

Conclusion

Nowadays, Egypt is facing water shortage problem and soil amending with different amendments can be one of the best strategies to overcome the water deficit, especially in sandy soils conditions. In the current study, biochar and superabsorbent polymer were used to improve the water holding capacity and water and fertilizer use efficiency of the sandy soil in which green pea (*Pisum sativum* L.) cv. Master B plants were grown under full irrigation (100% of water requirement) and water deficit (75% of water requirement) conditions. In conclusion, this study demonstrated that application of biochar (1% w/w) or/and superabsorbent polymer (0.7% w/w) significantly enhanced all parameters recorded under both full irrigation and water deficit conditions. Application of biochar along with superabsorbent polymer might be a novel strategy to improve the soil characteristics in the water-stressed regions and enhance the growth and productivity of crops.

Acknowledgement: The authors would like to acknowledge the Department of Horticulture, Faculty of Agriculture, Ain Shams University for allowing us to use their Experimental Farm. We would also like to thank Dr. Salama Abd El-Hameid Abd El-Hady for his invaluable help in the field. We would also like to thank the two anonymous reviewers for their constructive comments and improvements to the manuscript.

Funding statements: The authors declare that they did not receive any external funding for this study.
Conflict of interest: The authors declare that they have no competing interests.

References

Abbas, T., Rizwan, M., Ali, S., Rehman, M.Z., Qayyum, M.F., Abbas, F., Hannan, F., Rinklebe, J. and Ok, Y.S. (2017) Effect of biochar on cadmium bioavailability and uptake in wheat (*Triticum aestivum* L.) grown in a soil with aged contamination. *Ecotoxicology and Environmental Safety*, **140**, 37-47. doi: 10.1016/j.ecoenv.2017.02.028

Abedi-Koupai, J. and Asadkazemi, J. (2006) Effects of a hydrophilic polymer on the field performance of an ornamental plant (*Cupressus arizonica*) under reduced irrigation regimes. *Iranian Polymer J.*, **15** (9), 715-725.

Abel, S., Peters, A., Trinks, S., Schonsky, H., Facklam, M. and Wessolek, G. (2013) Impact of biochar and hydrochar addition on water retention and water repellency of sandy soil. *Geoderma*, **202-203**, 183-191. doi:10.1016/j.geoderma.2013.03.003

Afshar, R.K., Hashemi, M., DaCosta, M., Spargo, J. and Sadeghpour, A. (2016) Biochar application and drought stress effects on physiological characteristics of *Silybum marianum*. *Communications in Soil Science and Plant Analysis*, **47** (6), 743-752. doi:10.1080/00103624.2016.1146752

Ahmed, E.M., Aggor, F.S., Nada, S.S. and Hawash, S.I. (2015a) Synthesis and characterization of super absorbent polymers for agricultural purposes. *Int. J. Sci. Eng. Res.*, **6** (3), 282-287.

Ahmed, E.M., El-Tohamy, W.A., El-Abagy, H.M.H., Aggor, F.S. and Nada, S.S. (2015b) Response of snap bean plants to super absorbent hydrogel treatments under drought stress conditions. *Current Science International*, **4** (3), 467-472.

Akhtar, S.S., Li, G., Andersen, M.N. and Liu, F. (2014) Biochar enhances yield and quality of tomato under reduced irrigation. *Agricultural Water Management*, **138**, 37-44. doi:10.1016/j.agwat.2014.02.016

Akhter, J., Mahmood, K., Malik, K.A., Mardan, A., Ahmad, M. and Iqbal, M.M. (2004) Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. *Plant Soil Environ.*, **50** (10), 463-469.

AOAC (2016) "*Official Methods of Analysis*", 20th ed. Association of Official Analytical Chemists-International (AOAC), Gaithersburg, Maryland, USA.

Bamminger, C., Poll, C., Sixt, C., Högy, P., Wüst, D., Kandeler, E. and Marhan, S. (2016) Short-term response of soil microorganisms to biochar addition in a temperate agroecosystem under soil warming. *Agriculture, Ecosystems & Environment*, **233** (3), 308-317. doi:10.1016/j.agee.2016.09.016

Barrs, H.D. and Weatherley, P.E. (1962) A re-examination of the relative turgidity technique for estimating water deficits in leaves. *Aust. J. Biol. Sci.*, **15** (3), 413-428. doi:10.1071/BI9620413

Batool, A., Taj, S., Rashid, A., Khalid, A., Qadeer, S., Saleem, A.R. and Ghufran, M.A. (2015) Potential of soil amendments (biochar and gypsum) in increasing water use efficiency of *Abelmoschus esculentus* L. Moench. *Front. Plant Sci.*, **6** (Article733), 1-13. doi:10.3389/fpls.2015.00733

Beesley, L. and Marmiroli, M. (2011) The immobilisation and retention of soluble arsenic, cadmium and zinc by biochar. *Environ. Pollut.*, **159** (2), 474-480. doi: 10.1016/j.envpol.2010.10.016

Beig, A.V.G., Neamati, S.H., Tehranifar, A. and Emami, H. (2014) Evaluation of chlorophyll fluorescence and biochemical traits of lettuce under drought stress and super absorbent or bentonite application. *Journal of Stress Physiology & Biochemistry*, **10** (1), 301-315.

Bodah, E.T., Braunwart, K., Bodah, B.W. and Alcindo Neckel, A. (2015) A rapid morphological screening procedure for pea (*Pisum sativum* L.) under drought stress in greenhouse settings. *American Journal of Experimental Agriculture*, **8** (1), 68-74. doi:10.9734/ajea/2015/16669

Bonanomi, G., Ippolito, F. and Scala, F. (2015) A "black" future for plant pathology: Biochar as a new soil amendment for controlling plant diseases. *J. Plant Pathol.*, **97**, 223-234.

Chapman, H.D. and Pratt, P.F. (1961) "*Methods of Analysis for Soils*", plants and water. University of California, Berkeley, USA.

Dodd, I.C. (2007) Soil moisture heterogeneity during deficit irrigation alters root-to shoot signalling of abscisic acid. *Funct. Plant Biol.*, **34**, 439-448. doi:10.1071/FP07009

Egamberdieva, D., Reckling, M. and Wirth, S. (2017) Biochar-based Bradyrhizobium inoculum improves growth of lupin (Lupinus angustifolius L.) under drought stress. *European Journal of Soil Biology*, **78**, 38-42. doi:10.1016/j.ejsobi.2016.11.007

El Sagan, M.A.M. (2015) Effect of polymer on drought tolerance of tomato (*Solanum lycopersicum* L.). *European Journal of Academic Essays*, **2** (9), 72-82.

El-Tohamy, W.A., El-Abagy, H.M.H., Ahmed, E.M., Aggor, F.S. and Hawash, S.I. (2014) Application of super absorbent hydrogel poly (acrylate/acrylic acid) for water conservation in sandy soil. *Transaction of the Egyptian Society of Chemical Engineering*, **40** (2), 1-8.

FAOSTAT (2014) Food and Agriculture Organizations of the United Nations. Statistics division. http://www.fao.org/faostat/en/#data/QC. Accessed 8 Jul 2017

Farooq, M., Hussain, M., Wahid, A. and Siddique, K.H.M. (2012) Drought stress in plants: an overview. In: Aroca, R. (Ed.), Plant Responses to Drought Stress. Springer, Berlin Heidelberg, pp. 1-33.

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D. and Basra, S.M.A. (2009) Plant drought stress: effects, mechanisms and management. *Agron. Sustain. Dev.*, **29** (1), 185-212. doi:10.1051/agro:2008021

Fernando, T.N., Aruggoda, A.G.B., Disanayaka, C.K. and Kulathunge, S. (2014) Evaluating the effects of different watering intervals and prepared soilless media incorporated with a best weight of super absorbent polymer (SAP) on growth of tomato. *Journal of Engineering and Technology of the Open University of Sri Lanka (JET-OUSL)*, **2** (2), 1-14.

Fiaz, K., Danish, S., Younis, U., Malik, S.A., Raza Shah, M.H. and Niaz, S. (2014) Drought impact on Pb/Cd toxicity remediated by biochar in *Brassica campestris*. *J. Soil Sci. Plant Nutri.*, **14** (4), 845-854. doi:10.4067/S0718-95162014005000067

Flexas, J., Bota, J., Loreto, F., Cornic, G. and Sharkey, T.D. (2004) Diffusive and metabolic limitations to photosynthesis under drought and salinity in C3 plants. *Plant Biol.*, **6** (3), 269-279. doi:10.1055/s-2004-820867

Glaser, B., Lehmann, J. and Zech, W. (2002) Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal-a review. *Biol. Fertil. Soils*, **35** (4), 219-230. doi:10.1007/s00374-002-0466-4

Hammer, E.C., Forstreuter, M., Rillig, M.C. and Kohler, J. (2015) Biochar increases arbuscular mycorrhizal plant growth enhancement and ameliorates salinity stress. *Applied Soil Ecology*, **96**, 114-121. doi:10.1016/j.apsoil.2015.07.014

Herbinger, K., Tausz, M., Wonisch, A., Soja, G., Sorger, A. and Grill, D. (2002) Complex interactive effects of drought and ozone stress on the antioxidant defence systems of two wheat cultivars. *Plant Physiol. Biochem.*, **40**, 691-696. doi:10.1016/S0981-9428(02)01410-9

Inyang, M.I., Gao, B., Yao, Y., Xue, Y., Zimmerman, A., Mosa, A., Pullammanappallil, P., Ok, Y.S. and Cao, X. (2016) A review of biochar as a low-cost adsorbent for aqueous heavy metal removal. *Crit. Rev. Environ. Sci. Technol.*, **46**, 406-433. doi:10.1080/10643389.2015.1096880

Jaiswal, A.K., Frenkel, O., Elad, Y., Lew, B. and Graber, E.R. (2015) Non-monotonic influence of biochar dose on bean seedling growth and susceptibility to *Rhizoctonia solani*: the "Shifted Rmax-Effect". *Plant Soil,* **395,** 1–16. doi:10.1007/s11104-014-2331-2

Jovanović, Ž., Stanisavljević, N., Mikić, A., Radović, S. and Maksimović, V. (2013) The expression of drought responsive element binding protein (*DREB2A*) related gene from pea (*Pisum sativum* L.) as affected by water stress. *Australian Journal of Crop Science (AJCS)*, **7** (10), 1590-1596.

Kamal, A.M. and El-Shazly, M.M. (2013) Maximizing the productivity and water use efficiency of tomato plants (*Lycopersicon esculentum* mill.) cultivated in the new reclaimed lands using different irrigation water quantities and some water saving substances. *J. Plant Production, Mansoura Univ.*, **4** (9), 1399-1416.

Khadem, S.A., Galavi, M., Ramrodi, M., Mousavi, S.R., Rousta, M.J. and Rezvani-moghadam, P. (2010) Effect of animal manure and superabsorbent polymer on corn leaf relative water content, cell membrane stability and leaf chlorophyll content under dry condition. *Australian Journal of Crop Science*, **4** (8), 642-647.

Kiatkamjornwong, S. (2007) Superabsorbent polymers and superabsorbent polymer composites. *ScienceAsia*, **33** (1), 39-43. doi:10.2306/scienceasia1513-1874.2007.33(s1).039

Kim, H.S., Kim, K.R.,Yang, J.E., Ok, Y.S., Owens, G., Nehls, T., Wessolek, G. and Kim, K.H. (2016) Effect of biochar on reclaimed tidal land soil properties and maize (*Zea mays* L.) response. *Chemosphere*, **142**, 153-159. doi:10.1016/j.chemosphere.2015.06.041

Kim, S., Iyer, G., Nadarajah, A., Frantz, J.M. and Spongberg, A.L. (2010) Polyacrylamide hydrogel properties for horticultural applications. *International Journal of Polymer Analysis and Characterization*, **15** (5), 307-318. doi:10.1080/1023666X.2010.493271

Lehmann, J., da Silva, J.P., Steiner, C., Nehls, T., Zech, W. and Glaser, B. (2003) Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. *Plant and Soil*, **249**, 343-357. doi:10.1023/A:1022833116184

Lehmann, J. and Joseph, S. (2015) "*Biochar for Environmental Management: Science, Technology and Implementation*". Earthscan Ltd. Publisher, London, UK, 976 pages

Liu, C., Liu, F., Ravnskov, S., Rubæk, G.H., Sun, Z. and Andersen, M.N. (2017) Impact of wood biochar and its interactions with mycorrhizal fungi, phosphorus fertilization and irrigation strategies on potato growth. *J. Agro. Crop Sci.*, **203** (2), 131-145. doi:10.1111/jac.12185

Liu, X., Zhang, A., Ji, C., Joseph, S., Bian, R., Li, L., Pan, G. and Paz-Ferreiro, J. (2013) Biochar's effect on crop productivity and the dependence on experimental conditions–a meta-analysis of literature data. *Plant Soil*, **373**, 583-594. doi:10.1007/s11104-013-1806-x

Mehraban, A. and Afrazeh, H. (2014) The effect of irrigation intervals and consumption of super absorbent polymers on yield and yield components of the local mung beans in Khash region. *Advances in Environmental Biology*, **8** (25), 118-121.

Moran, J.F., Becana, M., Iturbe-Ormaetxe, I., Frechilla, S., Klucas, R.V. and Aparicio-Tejo, P. (1994) Drought induces oxidative stress in pea plants. *Planta*, **194** (3), 346-352. doi:10.1007/BF00197534

Nadeem, S.M., Imran, M., Naveed, M., Khan, M.Y., Ahmad, M., Zahir, Z.A. and Crowley, D.E. (2017) Synergistic use of biochar, compost and plant growth-promoting rhizobacteria for enhancing cucumber growth under water deficit conditions. *J. Sci. Food Agric.*, **97** (15)**,** 5139-5145. doi: 10.1002/jsfa.8393.

Odesola, I.F. and Owoseni, T.A. (2010) Small scale biochar production technologies: a review. *J. Emerg. Trends Eng. Appl. Sci.*, **1** (2), 151-156.

Ok, Y.S., Chang, S.X., Gao, B. and Chung, H.J. (2015) SMART biochar technology-a shifting paradigm towards advanced materials and healthcare research. *Environ. Technol. Innov.*, **4**, 206-209. doi:10.1016/j.eti.2015.08.003

Orzeszyna, H., Garlikowski, D. and Pawlowski, A. (2006) Using of geocomposite with superabsorbent synthetic polymers as water retention element in vegetative layers. *Int. Agrophysics*, **20**, 201-206

Osakabe, Y., Osakabe, K., Shinozaki, K. and Tran, L.S.P. (2014) Response of plants to water stress. *Frontiers Plant Sci.*, **5** (Article 86), 1-8. doi:10.3389/fpls.2014.00086

Osman, H.S. (2015) Enhancing antioxidant–yield relationship of pea plant under drought at different growth stages by exogenously applied glycine betaine and proline. *Annals of Agricultural Sciences*, **60** (2), 389-402. doi:10.1016/j.aoas.2015.10.004

Piper, C.S. (1950) "*Soil and Plant Analysis*", 1st ed. Interscience Publishers, New York, USA, pp 30-59.

Pouresmaeil, P., Habibi, D. and Boojar, M.M.A. (2012a) Yield and yield component quality of red bean (*Phaseolus vulgaris* L.) cultivars in response to water stress and super absorbent polymer application. *Annals of Biological Research*, **3** (12), 5701-5704.

Pouresmaeil, P., Habibi, D., Boojar, M.M.A., Tarighaleslami, M. and Khoshouei, S. (2012b) Effects of superabsorbent application on agronomic characters of red bean (*Phaseolus vulgaris* L.) cultivars under drought stress conditions. *Intl. J. Agri. Crop Sci.*, **4** (24), 1874-1877.

Pouresmaeil, P., Habibi, D., Boojar, M.M.A., Tarighaleslami, M. and Khoshouei, S. (2013) Effect of super absorbent polymer application on chemical and biochemical activities in red bean (*Phaseolus volgaris* L.) cultivars under drought stress. *European Journal of Experimental Biology*, **3** (3), 261-266.

Qayyum, M.F., Abid, M., Danish, S., Saeed, M.K. and Ali, M.A. (2015) Effects of various biochars on seed germination and carbon mineralization in an alkaline soil. *Pak. J. Agri. Sci.*, **51**(4), 977-982.

Rezaei, A., Yazdanpanah, M., Khosrotaj, Z., Bahreman, Z., Poureidi, S., Rashnavadi, R. and Khosravi, B. (2014) Effect of drought stress on yield and yield components of pea hybrids. *Tech. J. Engin. & Appl. Sci.*, **4** (4), 324-327.

Safavi, F., Galavi, M., Ramroodi, M. and Chaman, M.R.A. (2016) Effect of super absorbent polymer, potassium and manure animal to drought stress on qualitative and quantitative traits of pumpkin (*Cucurbita pepo*). *Intl. J. Farm & Alli. Sci.*, **5** (4), 330-335.

Sarvaš, M., Pavlenda, P. and Takáčová, E. (2007) Effect of hydrogel application on survival and growth of pine seedlings in reclamations. *J. For. Sci.*, **53** (5), 204-209.

Shahrokhian, Z., Mirzaei, F. and Heidari, A. (2013) Effects of super absorbent polymer on tomato's yield under water stress conditions and its role in the maintenance and release of nitrate. *World Rural Observations*, **5** (2), 15-19.

Shinde, B.P. and Thakur, J. (2015) Influence of arbuscular mycorrhizal fungi on chlorophyll, proteins, proline and total carbohydrates content of the pea plant under water stress condition. *Int. J. Curr. Microbiol. App. Sci.*, **4** (1), 809-821.

Sorensen, J.N., Edelenbos, M. and Wienberg, L. (2003) Drought effects on green pea texture and related physical–chemical properties at comparable maturity. *J. Amer. Soc. Hort. Sci.*, **128** (1), 128-135.

Taiz, L., Zeiger, E., Møller, M. and Murphy, A. (2015) "*Physiology and Development*", 6th ed. Sinauer Associates, Sunderland, Miami, USA.

Tardieu, F., Parent, B., Caldeira, C.F. and Welcker, C. (2014) Genetic and physiological controls of growth under water deficit. *Plant Physiol.*, **164** (4), 1628-1635. doi: 10.1104/pp.113.233-353.

Thomas, R.L., Sheard, R.W. and Moyer, J.R. (1967) Comparison of conventional and automated procedures for nitrogen, phosphorus and potassium analysis of plant materials using a single digestion. *Agron. J.*, **59**, 240-243.

Yang, L., Yang, Y., Chen, Z., Guo, C. and Li, S. (2014) Influence of super absorbent polymer on soil water retention, seed germination and plant survival for rocky slopes eco-engineering. *Ecological Engineering*, **62**, 27-32. doi:10.1016/j.ecoleng.2013.10.019.

Yazdani, F., Allahdadi, I. and Akbari, G.A. (2007) Impact of superabsorbent polymer on yield and growth analysis of soybean (*Glycine max* L.) under drought stress condition. *Pak. J. Biol. Sci.*, **10** (23), 4190-4196. doi:10.3923/pjbs.2007.4190.4196 .

(*Received* 16/05/2018;
accepted 27/05/2018

إمداد الأراضي الرملية بالفحم النباتي الحيوي أو/و البوليمرات فائقة الإمتصاص يخفف من التأثيرات الضارة لإجهاد الجفاف على البسلة الخضراء

جمال الدين سمير رياض*، صبري موسى سليمان يوسف** ، نشوه عطية إبراهيم أبوالعزم** و إيناس أحمد***

* قسم بحوث الخضر - المركز القومي للبحوث - القاهرة ** قسم البساتين- كلية الزراعة - جامعة عين شمس - القاهرة و *** قسم الهندسة الكيماوية والتجارب نصف الصناعية - المركز القومي للبحوث - القاهرة - جمهورية مصر العربية.

في مواجهة ندرة الموارد المائية والتغيرات المناخية، فإن الجفاف بلا شك هو أحد أهم الإجهادات التي تحد من نمو وإنتاجية النباتات بما في ذلك البسلة الخضراء، وخاصة في المناطق القاحلة وشبه القاحلة. إن إستخدامات محسنات التربة مثل الفحم النباتي الحيوي والبوليمرات الفائقة الإمتصاص والتي تتميز بقدرتها على الإحتفاظ بالماء وتحسين الخصائص الفيزيائية للتربة ستصبح أكثر أهمية في هذه المناطق. أجريت تجربة ليزوميتر تحتوي على تربة رملية في تصميم عشوائي كامل في ثلاثة مكررات لدراسة تأثير الفحم النباتي الحيوي أو/و البوليمرات الفائقة الإمتصاص على نمو وإنتاجية البسلة الخضراء صنف ماستر بي تحت معدلات الري الكامل (١٠٠٪ من الإحتياجات المائية) ونقص المياه (٧٥٪ من الإحتياجات المائية) خلال موسمي النمو ٢٠١٦/٢٠١٥ و ٢٠١٧/٢٠١٦ في المزرعة البحثية لقسم البساتين بكلية الزراعة، جامعة عين شمس محافظة القليوبية، مصر. أوضحت النتائج أن خفض مستوى الري إلى ٧٥٪ من الاحتياجات المائية أدى إلى إنخفاض معنوي في صفات النمو الخضري وقراءات SPAD ومحتوى الماء النسبي للأوراق ومحتوى الأوراق من النيتروجين، الفوسفور والبوتاسيوم ومكونات محصول القرون مقارنة مع الري الكامل. أدت إضافة الفحم النباتي الحيوي أو/و البوليمرات الفائقة الإمتصاص إلى زيادة معنوية في القياسات سالفة الذكرتحت كلا من ظروف الري الكامل ونقص المياه. وكانت إضافة الفحم النباتي الحيوي والبوليمرات الفائقة الإمتصاص معاً الأكثر كفاءة للتخفيف من التأثيرات الضارة لنقص المياه على زراعة البسلة الخضراء في التربة الرملية. وتخلص الدراسة إلى أن إضافة الفحم النباتي الحيوي (١٪ وزن/وزن) مع والبوليمرات الفائقة الإمتصاص (٠,٧٪ وزن/وزن) يمكن أن يكون نهجاً جديداً لتحسين خصائص التربة الرملية ويساعد على زراعة البسلة الخضراء في هذه التربة التي تتميز بظروف محدودية المياه وفقرها في العناصر الغذائية.