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Impact of Biochar Addition on Productivity and Tubers Quality of Some Potato Cultivars Under Sandy Soil Conditions

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THE PRESENT study was carried out during the two summer seasons of 2016 and 2017 to study the effect of biochar application rates (0, 1.25, 2.5 and 5 m^3/feddan (fed.) = 4200 m^2) on productivity and tubers quality of three potato cultivars i.e., Accent, Cara and Spunta grown under sandy soil conditions. Cara and Spunta cultivars recorded the highest values of morphological traits, leaf content of Ca, Mn and Cu, as well as tuber yield and quality. Cara cultivar recorded the maximum dry weight of different plant parts, while Spunta cv. recorded the highest values of photosynthetic pigments concentrations in the leaf tissues and the highest tuber starch content. Accent cv. recoded the lowest values of the last mentioned parameters and the lowest tuber nitrate content. Plant growth, leaf photosynthetic pigments and minerals content (N, P, K, Ca, Fe, Zn, Mn, and Cu), yield and its components, as well as tuber quality were significantly increased with increasing biochar application rates up to 5 m^3/fed. Treated the three tested potato cultivars plants with different application rates of biochar increased plant growth, leaf photosynthetic pigments, minerals content and tuber yield and its components, compared to those untreated with biochar. Adding biochar at rates of 2.5 or 5 m^3/fed. to the three tested potato cultivars Considerably gave the lowest values of leaf nitrate content. Treating Cara cultivars with biochar at rate of 5 m^3/fed. gave the highest values of gross and net return, as well as benefits ratio, followed by adding 5 m^3/fed. to Spunta plants. Finally, adding biochar to potato plants grown in sandy soil conditions obviously improves potato plant growth, plant chemical compositions, tuber yield and its components, with good tubers quality and increasing net return of potato production and keeps the environment less polluted.

Keywords: *Solanum tuberosum,* Plant growth, Chemical composition, Yield, Feasibility study.

Introduction

Potato (*Solanum tuberosum,* L.) is one of the most important vegetables in Egypt for both local consumption and exportation. It has a considerable importance as an export crop to the European and Arab markets and one of the national income resources. The total potato cultivated area in 2015 in Egypt, was 437,386 Feddan (fed.), which produced 4,955,445 tons with average 11.33 ton/fed. (Ministry of Agriculture and Land Reclamation, 2015).

The choice of cultivar plays a significant role in potato production (Burton, 1989), the planted cultivar must satisfy both the grower, in terms of yield, maturity, pests and diseases resistance… *etc.*, and also the consumer, especially in terms of price and quality. The origin of potato cvs. Accent and Spunta is Holland, while Cara cultivar is Ireland. Vakis (1990) found that Spunta cv. gave the highest values of tubers yield, followed by Cara cv., whereas Accent cv. gave the lowest values.

It is well known that sandy soil is low in its fertility and water retention, and has poor physical, chemical and biological properties with high soil pH. Biochar is an organic amendment produced by the process called pyrolysis, which is the burning biomass in a limited or absence of oxygen (Nair et al., 2014). Biochar application has the potential to improve crop productivity, but the effect of biochar application was highly dependent on soil fertility and fertilizer management (Asai et al., 2009). Using biochar as a soil conditioner increased soil fertility, reduced fertilizers need while maintaining or improving crop productivity, reduced nutrient leaching, increased microbial activity in soil, improved water retention capacity and water use efficiencies, and cation exchange capacity in both sandy and clay soils. Biochar has also a potential to significantly improve durability of soil aggregates and reduce erosion and also

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has the potential to mitigate climate change by sequestering carbon into soils (Lehmann et al., 2006 and 2009, Jha et al., 2010, Jeffery et al., 2011, Hale, 2013, Sun and Lu, 2014).

Graber et al. (2010) mentioned that treating tomato plants by biochar positively enhanced plant height and leaf size. Also, biochar addition to mineral fertilizers significantly increased plant growth (Schulz and Glaser, 2012, Biederman and Harpole, 2013). The biochar treatments were found to increase the final vegetative biomass, root biomass, plant height and leaf number of lettuce and cabbage in all the cropping cycles compared to no biochar treatments (Carter et al., 2013). Furthermore, Biochar as previously mentioned is an amendment that can be used for enhancing soil moisture content which may increase the crop productivity. In this respect, Akhtar et al. (2014) indicated that addition of biochar increased the soil moisture contents, which consequently improved physiology, yield, and quality of tomato plants. In addition, Nair (2015), on potato cv. Atlantic, found that there was a general trend of increasing yields with increasing biochar application rates but differences were not statistically significant. Similarly, microbial biomass carbon also was increased with higher biochar application rates but did not show any significant differences. The crop yields increases due to biochar application have been attributed to better water holding capacity, higher cation exchange capacity, increased nutrient retention, and the ability of biochar to reduce bulk density. Biochar could be a valuable tool for management of soils that are either degraded or have poor nutrient status; however, it could take time to detect significant changes in soil and crop attributes after biochar addition.

Dou et al. (2012) revealed that biochar treatment could increase yield, sugar content and appearance quality of sweet potato, which was conducive to bringing more economic profits for farmers, and improving food safety through using organic fertilizers, and finally promoting sustainable crop production. Researches on field crops production had shown promising results with biochar treatment, but, research on vegetables is late and very few. So the aim of this study was to investigate the effects of biochar as a soil conditioner on yield and tuber quality of some potato cultivars grown in sandy soil.

Materials and Methods

This study was carried out during the two successive summer seasons of 2016 and 2017 at El-Kassasein Horticulture Experimental Farm, Ismailia Governorate (Egypt), Horticulture Research Institute, Agricultural Research Center to study the effect of biochar addition on the production of some potato cultivars (Accent, Cara and Spunta) grown in sandy soil conditions. Random samples were collected from the experimental soil field location and used biochar at the beginning of the experiment in the two seasons to determine physical and chemical properties according to the methods described by Jakson (1970) as shown in Table (1).

TABLE 1. The physical and chemical properties of the experimental soil and used biochar*.

Soil		Season		Biochar		Season	
		2016	2017			2016	2017
Physical properties (%)				Chemical properties			
Sand		94.83	95.11	Total % (DW)	C	30.66	31.49
Silt		3.98	3.32		N	0.82	0.78
Clay		1.14	1.52		S	0.08	0.10
Organic matter		0.05	0.05				
Field capacity (F.C.)		8.92	8.52	mg/kg	P	17.53	18.16
Wilting point (W.P.)		3.89	3.98		K	315.00	306.00
Texture class		Sandy			Ca	655.00	698.00
Chemical properties					Mg	187.00	192.00
					Na	898.00	863.00
Available (ppm)	N	3.82	3.98		Fe	76.13	77.22
	P	3.14	3.76		Mn	161.00	172.00
	K	8.55	9.65		Zn	12.89	12.67
Electric conductivity (E.C.) mmhos/cm		2.83	2.79		Cu	9.39	10.21
pH (1:2.5 suspension)		8.43	8.56	pH (1:2.5 suspension)		9.43	10.08

*Soil samples were taken from 25 cm of soil surface.

This experiment included 12 treatments, which were the combinations between three potato cvs. (Accent, Cara, and Spunta) and 4 amounts of biochar (0.00, 1.25, 2.50, and 5.00 m^3/fed.). These treatments were arranged in a split plot design with 3 replicates. The potato cultivars were randomly distributed in the main plots and biochar application rates were randomly arranged in the sub plots. Plot area was 14.6 m^2 and contained 3 rows with 6.5 m length and 75 cm width. One row was used to measure the vegetative growth parameters and the other two rows were used for measuring tuber yield and its components. Drip irrigation system was used and the distance between drippers was 50 cm. Tuber seeds of the three tested potato cultivars (Accent, Cara and Spunta) were obtained from Hort. Res. Inst., Agric. Res. Cent., Egypt.

Potato tubers seed were planted on the summer plantation in February 2nd and January 26th in 2016 and 2017 seasons, respectively. Tuber seeds were planted in hills on one side of ridge spaced at 25 cm apart. The average weight of potato tuber seed was about 60 g. The sources of nitrogen, phosphorus and potassium fertilizers were ammonium nitrate (33% N) or ammonium sulfate (20.6% N), calcium superphosphate (15.5% P_2O_5) and potassium sulfate (48 - 52% K_2O), respectively. One third of nitrogen and potassium sulfate fertilizers amount and all calcium superphosphate amounts were added during soil preparation with application of farmyard manure (30 m^3/fed.) and biochar rates (0.00, 1.25, 2.50 and 5.00 m^3/fed.) in the center of rows and covered by soil. The rest of ammonium nitrate and potassium sulfate were divided into 30 equal portions and then added to the plant every two days, beginning 20 days after planting through irrigation water (fertigation system). The fertilization was stopped after 80 days after planting. The other normal recommended agricultural practices for commercial potato production were carried out as recommended by Egyptian Ministry of Agriculture and Land Reclamation.

Data recorded

Vegetative plant growth parameters

A random sample of 6 plants was taken from every experiential replicate after 75 days after planting in both seasons to determine the following parameters:

Morphological traits: plant height (cm), numbers of main (aerial) stems, leaves and tubers/plant, as well as leaf area/plant (cm^2).

Dry weight: Different plant parts (roots, stems, leaves and tubers) were dried at 70ºC in an oven till constant weight as reached according to Dogras et al. (1991) and the following data were recorded: Dry weights of roots, stems, leaves, tubers and total dry weight [roots + stems + leaves + tubers] (g)/plant and relative total dry weight (%).

Plant chemical compositions

Leaf photosynthetic pigments: A random sample from the fourth upper leaf of potato plants was taken from every plot after 75 days after planting, in the two growing seasons, to determine chlorophyll a and b, as well as, carotenoids according to the method described by Jeffry and Humphrey (1975).

Leaf minerals content: The dry leaves after 75 days after planting were finely pulverized and wet digested for N, P, K, Ca, Fe, Mn, Zn, Cu and nitrate determination. The major elements (N, P, K and Ca) were determined according to the methods described by Bremner and Mulvaney (1982), Olsen and Sommers (1982), Jackson (1970), and Cheng and Bray (1951), respectively. The minor elements (Fe, Mn, Zn and Cu) were determined according to the methods described by AOAC (1990).Nitrate content was determined according to the method described by Catado et al. (1975).

Tuber Yield and its components

At harvest time (115 days after planting) tubers from each experiential replicate were weighed, counted and graded into three sizes according to specification of potato exportation laid down by the Ministry of Economic (1963), as follows: Grade 1: tubers with diameter above 55 mm, Grade 2: tubers with diameter between 35 - 54 mm, and Grade 3: tubers with diameter less than 35 mm, and after that each grade was weighed separately. Also, the following data were recorded: Number of tubers/plant, average tuber weight (g), tuber yield per plant (g), yield of grades 1, 2 and 3, marketable yield (yield of grades 1 + 2), total yield (yield of grades 1 + 2 + 3) ton/fed., and relative total yield (%).

Tuber quality

N, P, K and nitrate contents were determined in tubers at harvest time as previously mentioned in the plant chemical composition (leaf minerals content).

Total protein content (%) was calculated by multiplying total N × 6.25, as described by Pregl (1945).

Total carbohydrate content **(%)** was determined calorimetrically in dry tubers, as described by the method of Michel et al. (1959).

Starch content **(%)** in tuber was determined according to AOAC (1990) methods.

Dry matter content **(%)**: 100 g of the potato tubers grated mixture were dried at 105°C till constant weight and DM content (%) was recorded.

Specific gravity (SG) was determined according to the method of Murphy and Govern (1959). Whereas, the tubers were weighed in the air (a) and then in water (b) and **S.G.** was calculated by the formula: SG = a / a - b

Feasibility study

Cost benefits analysis: The cost of production was analyzed with a view of finding out the most profitable treatments. All the non material and material input costs and interests on running capital were considered for computing the production cost. Cost and return analysis were done in details according to the procedure of Perkins (1994). Benefit cost ratio was calculated by the following formula:
Benefit cost ratio = Gross return (Egyptian Pounds (L.E.)/fed.) / Total cost of production (L.E.)/fed.

Statistical analysis

The data of this experiment were subjected to proper statistical analysis of variance according to Snedecor and Cocharan (1989) and means separation were done according to L.S.D. at 5% level.

Results and Discussion

Plant growth

Morphological traits

There were significant differences among the three potato cultivars (Accent, Cara and Spunta) with respect to plant height, number of main stems, leaves and tubers/plant, as well as leaf area/plant, except plant height in the second season (Table 2). Cultivars Cara and Spunta recorded the tallest plants and gave the highest values of number of main stems, leaves and tubers/plant and leaf area/plant at 75 days after planting, whereas Accent cultivar recoded the shortest plants and gave the lowest values of number of main stems, leaves and tubers/plant, as well as leaf area/plant.

Concerning the effect of biochar application, data presented in Table (2) show that potato plants grown in sandy soil applied with biochar had a significant response in respect of plant height, number of main stems, leaves and tubers/plant and leaf area/plant in both studied seasons. Potato plants grown in sandy soil amended with different biochar application rates had better morphological traits compared to control (without biochar) in both seasons. Plant height, number of main stems, leaves and tubers/plant and leaf area/plant significantly increased with increasing biochar application rates up to 5 m^3/fed. In this respect, Graber et al. (2010) emphasized that treating tomato plants by biochar positively enhanced plant height and leaf size. Carter et al. (2013) confirmed that the biochar treatments were increased the final biomass, root biomass, plant height and leaf number of lettuce and cabbage in all the cropping cycles. Also, biochar addition to mineral fertilizers significantly increased plant growth (Schulz and Glaser, 2012, Biederman and Harpole, 2013).

The obtained results in Table 2 indicated that the interaction between cultivars and biochar application rates had a significant effect on morphological traits. Fertilizing all tested potato plants cultivars with different rates of biochar (1.25, 2.5 and 5 m^3/fed.) markedly increased morphological traits compared to the same cultivars grown without biochar application (control) in both seasons. Fertilizing with biochar at a rate of 5 m^3/fed. recorded the tallest plants, highest number of main stems, leaves and tubers/plant and leaf area/plant in all tested cultivars at 75 days after planting in both seasons, compared to the other interaction treatments.

Dry weight

Potato Cara cultivar recorded the maximum values of dry weight (DW) of roots, stems, leaves, tubers, as well as total dry weight/plant, followed by Spunta cultivar, whereas Accent cultivars recorded the lowest values of DW of roots, stems, leaves, tubers and total DW/plant in both studied seasons (Table 3). The increases in total DW/plant were about 13.69 and 11.63% for Cara cultivar and 6.93 and 5.59% for Spunta cv., over Accent cv. in the first and second seasons, respectively. These increases in total DW of Cara and Spunta cvs. may be due to that both potato cvs. Cara and Spunta recorded the maximum values of number of stems, leaves and tubers/plant, as well as leaf area/plant (Table 2).

TABLE 2. Effect of cultivars and biochar application on morphological traits of potato plants grown in sandy soil at 75 days after planting during 2016 and 2017 seasons.

Treatments		2016 Season					2017 Season				
		Plant height (cm)	Number/plant			Leaf area/ plant (cm^2)	Plant height (cm)	Number/plant			Leaf area/ plant (cm^2)
			Main stems	Leaves	Tubers			Main stems	Leaves	Tubers	
Cultivars											
Accent		65.99	4.52	60.58	11.41	2483	64.08	4.27	55.12	10.67	2748
Cara		70.35	5.15	66.61	12.89	2795	68.07	4.78	61.30	12.21	3103
Spunta		68.79	4.86	62.82	12.28	2564	66.08	4.52	58.90	11.47	2889
L.S.D. at 0.05 level		2.60	0.58	3.91	1.26	127	N.S.	0.35	3.28	1.14	117
Biochar (m^3/fed.)											
0.00		59.27	3.57	50.99	8.33	1891	57.23	3.11	42.90	7.78	2167
1.25		64.81	4.44	61.02	11.64	2199	63.30	3.93	55.97	10.06	2774
2.50		71.96	5.32	66.47	13.36	2890	68.19	4.93	64.14	12.33	3191
5.00		77.48	6.03	74.87	15.43	3476	75.58	6.11	70.74	15.61	3521
L.S.D. at 0.05 level		4.74	0.41	4.26	0.89	221	4.00	0.41	2.91	1.25	183
Cultivars × biochar interaction											
Cultivars	Biochar (m^3/ fed.)										
Accent	0.00	55.83	3.167	47.7	7.33	1731	54.80	2.77	37.57	7.00	1884
	1.25	63.03	4.07	59.47	11.23	2134	61.07	3.67	52.23	9.33	2671
	2.50	69.90	5.07	64.67	12.63	2648	66.77	4.53	61.33	11.50	3051
	5.00	75.20	5.77	70.47	14.43	3441	73.67	6.10	69.33	14.83	3384
Cara	0.00	62.77	3.93	55.13	9.10	2045	60.10	3.47	47.57	8.50	2494
	1.25	66.83	4.77	62.43	12.13	2111	64.90	4.23	59.33	10.83	2938
	2.50	73.67	5.67	69.33	13.90	3119	69.57	5.23	65.97	13.00	3332
	5.00	78.13	6.23	79.53	16.43	3662	77.70	6.20	72.33	16.50	3648
Spunta	0.00	59.20	3.60	50.10	8.57	1896	56.80	3.10	43.57	7.83	2123
	1.25	64.57	4.50	61.17	11.57	2353	63.93	3.90	56.33	10.0	2712
	2.50	72.30	5.23	65.40	13.53	2902	68.23	5.03	65.13	12.50	3191
	5.00	79.10	6.10	74.60	15.43	3325	75.37	6.03	70.57	15.50	3530
L.S.D. at 0.05 level		7.54	0.84	7.44	1.82	354	7.29	0.71	5.42	2.18	297

N.S.: Not significant at 0.05 level probability and Feddan (fed.) = 4200 m^2 = 0.42 hectare.

TABLE 3. Effect of cultivars and biochar application on dry weight of potato plants grown in sandy soil at 75 days after planting during 2016 and 2017 seasons.

Treatments		2016 Season						2017 Season					
		Dry weight (g)					Relative total DW (%)	Dry weight (g)					Relative total DW (%)
		Root	Stems	Leaves	Tubers	Total		Root	Stems	Leaves	Tubers	Total	
Cultivars													
Accent		3.63	9.55	38.02	98.36	149.56	100.00	2.99	11.08	36.73	115.82	166.62	100.00
Cara		4.05	10.94	45.75	109.29	170.03	113.69	3.30	12.21	40.54	129.94	185.99	111.63
Spunta		3.82	10.29	41.70	104.12	159.93	106.93	3.10	11.81	38.72	122.30	175.93	105.59
L.S.D. at 0.05 level		0.10	0.57	6.05	6.14	3.54	-	0.19	0.50	1.45	1.16	1.74	-
Biochar (m^3/fed.)													
0.00		2.97	8.48	30.67	83.62	125.74	100.00	2.54	9.36	30.54	100.02	142.46	100.00
1.25		3.51	9.14	37.89	96.37	146.91	116.84	2.92	11.04	36.28	114.45	164.69	115.60
2.50		4.20	10.71	43.21	109.00	167.12	132.91	3.36	12.46	40.57	127.29	183.68	128.93
5.00		4.65	12.71	55.52	126.69	199.57	158.72	3.70	13.94	47.24	149.00	213.88	150.13
L.S.D. at 0.05 level		0.26	1.10	8.26	6.55	8.02	-	0.21	0.45	3.21	7.45	9.76	-
Cultivars × biochar interaction													
Cultivars	Biochar m³/fed.)												
Accent	0.00	2.81	7.57	26.70	78.39	115.47	100.00	2.36	8.47	27.56	91.48	129.87	100.00
	1.25	3.30	8.57	37.02	91.95	140.84	121.97	2.80	10.67	34.43	109.98	157.88	121.57
	2.50	3.98	10.15	39.71	105.40	159.24	137.91	3.28	12.03	39.58	122.15	177.04	136.32
	5.00	4.41	11.89	48.65	117.69	182.64	158.17	3.52	13.16	45.33	139.68	201.69	155.30
Cara	0.00	3.18	9.27	34.57	89.67	136.69	118.38	2.77	9.96	32.66	106.83	152.22	117.21
	1.25	3.71	9.74	38.85	100.54	152.84	132.36	3.08	11.38	37.99	119.79	172.24	132.62
	2.50	4.35	11.30	47.55	113.40	176.60	152.94	3.45	12.82	41.79	133.48	191.54	147.49
	5.00	4.94	13.46	62.01	133.53	213.94	185.28	3.95	14.68	49.71	159.65	227.99	175.55
Spunta	0.00	2.91	8.59	30.73	82.79	125.02	108.27	2.54	9.66	31.40	101.76	145.36	111.93
	1.25	3.53	9.10	37.81	96.62	147.06	127.36	2.89	11.08	36.42	113.58	163.97	126.26
	2.50	4.27	10.68	42.36	108.22	165.53	143.35	3.37	12.52	40.35	126.22	182.46	140.49
	5.00	4.59	12.78	55.91	128.83	202.12	175.04	3.63	13.99	46.69	147.66	211.97	163.22
L.S.D. at 0.05 level		0.41	1.74	13.71	11.51	12.51	-	0.36	0.83	5.02	11.22	14.73	-

N.S.: Not significant at 0.05 level probability and Feddan (fed.) = 4200 m^2 = 0.42 hectare.

Fertilizing potato plants with biochar at different application rates (1.25, 2.5 and 5 m^3/fed.) markedly increased dry weight/plant, compared to control (Table 3). DW of roots, stems, leaves and up to 5m^3/fed. in both tested seasons. The increases in total DW/plant were about 16.84 and 15.60% tubers, as well as total DW/plant significantly increased with increasing of biochar application rate for biochar applied at 1.25 m^3/fed. over the control in the first and second seasons, respectively. While, such increases were about, 32.90 and 28.93% for biochar applied at 2.5 m^3/fed. and were about 58.72 and 50.13% for biochar applied at 5 m^3/fed. over the control in the first and second season, respectively.

These increases may be attributed to that fertilizing with biochar positively increased number of main stems, leaves and tubers, as

The interaction between potato cultivars and biochar application rates had a significant effect on dry weight of roots, stems, leaves and tubers as well as total DW/plant (Table 3). Generally, potato cvs. Accent, Cara and Spunta grown in sandy soil amended with different rates of biochar (1.25, 2.5 and 5 m^3/fed.) markedly increased DW of roots, stems, leaves and tubers, as well as total DW/plant, compared to the same cultivars grown in sandy soil without biochar. Treating Cara and Spunta grown in sandy soil with biochar at 5 m^3/fed. significantly increased DW of roots, stems, leaves and tubers as well as total DW/plant at 75 days after planting, compared to the other interactions in both seasons. The increases in total DW were about 85.28 and 75.55% for Cara cv. applied with 5 m^3/fed. of biochar and 75.04 and 63.20% for Spunta cv. applied with 5 m^3/fed. of biochar, over the Accent cv. grown without biochar in the first and second seasons, respectively.

Plant chemical compositions

Leaf photosynthetic pigments

There were significant differences among potato cultivars with respect to concentration of chlorophyll (Chl.) types, *i.e.* Chl. a and b, total Chl. (a + b), as well as carotenoids in leaf tissues (Tables 4 and 5). Potato cv. Spunta recorded the highest values of Chl. a, Chl. b and total Chl., as well as carotenoids in leaf tissues with no significant differences with Cara cv. in the first season, whereas Accent cv. recorded the lowest values of chlorophylls and carotenoids at 75 days after planting in both planting seasons.

The concentration of Chl. a and b and total Chl., as well as carotenoids in leaf tissues significantly increased with increasing biochar application rates up to 5 m^3/fed. (Tables 4 and 5). Potato plants grown with biochar at different rates had a higher concentration of chlorophylls and carotenoids in leaf tissues, compared to control (without biochar).

Treated potato cvs. Cara and Spunta grown in sandy soil amended with biochar at 5 m^3/fed. clearly increased the concentration of Chl. a and b and total Chl., as well as carotenoids in leaf tissues with no significant differences with Spunta cv. amended with biochar at 2.25 m^3/fed. in the first season (Tables 4 and 5).

Leaf minerals content

There were no significant differences among the three tested cultivars, *i.e.* Accent, Cara and Spunta in N and P contents in the first season, Fe content in the second season and K, Zn and nitrate content in both studied seasons (Tables 4 and 5). Generally, Cara and Spunta cultivars gave the highest content of Ca, Mn and Cu in leaves, followed by the Accent cultivar.

Contents of N, P, k, Ca, Fe, Zn, Mn, and Cu in potato leaves significantly increased with increasing biochar application up to 5 m^3/*fed*. with no significant differences with 2.5 m^3/fed. in the 1st season, whereas nitrate content in potato leaves significantly decreased with increasing biochar up to 5 m^3/fed. (Tables 4 and 5). Yamato et al. (2006) revealed that biochar can lead to changes in physical and chemical properties of the soil which resulted in an increase in nutrient availability in the soil and increases plant root colonization by mycorrhizal fungi.

The interaction between cultivars and biochar had a significant effect on mineral contents in potato leaves, except K and Zn contents in the second season (Tables 4 and 5). In general, the three tested potato cvs. Accent, Cara and Spunta applied with biochar at 2.5 or 5 m^3/fed. gave the lowest values of leaf nitrate content in both studied seasons. There was no clear trend for the effect of the interaction between potato cvs. and biochar application on minerals content, but, generally, treating the three potato cultivars with biochar at 5 m^3/fed. markedly increased contents of N, P, Ca, Fe, Zn, Mn, and Cu in potato leaves.

TABLE 4. Effect of cultivars and biochar application on photosynthetic pigments and minerals content of leaf potato plants grown in sandy soil at 75 days after planting during 2016 season.

Treatments		Photosynthetic pigments Chlorophyll (mg/100 g FW)				Minerals content								Nitrate content (mg/kg DW)
						%				ppm.				
		a	b	Total (a + b)	Caro-tenoides	N	P	K	Ca	Fe	Zn	Mn	Cu	
Cultivars														
Accent		93.73	48.11	141.84	77.53	3.54	0.337	3.45	0.291	334.6	22.8	19.7	19.5	314.6
Cara		101.48	50.39	151.88	79.25	3.65	0.352	3.61	0.318	345.0	24.2	24.2	23.0	321.6
Spunta		107.50	52.03	159.53	81.36	3.62	0.345	3.53	0.323	338.8	23.5	22.3	21.3	320.2
L.S.D. at 0.05 level		6.88	2.69	9.22	1.02	N.S.	N.S.	N.S.	0.021	2.8	N.S.	2.3	2.4	N.S.
Biochar (m^3/fed.)														
0.00		81.62	41.53	123.16	70.76	3.29	0.312	3.17	0.283	315.3	19.8	19.3	18.2	357.6
1.25		95.73	47.76	143.49	77.94	3.51	0.329	3.40	0.293	332.3	21.9	19.9	20.4	339.7
2.50		107.86	52.51	160.37	82.90	3.72	0.353	3.68	0.318	346.4	24.9	24.0	23.2	302.7
5.00		118.41	58.91	177.32	85.91	3.87	0.384	3.86	0.349	363.8	27.4	25.0	23.1	275.2
L.S.D. at 0.05 level		6.70	4.53	9.56	2.86	0.30	N.S.	0.28	0.035	3.0	3.4	2.3	1.7	22.7
Cultivars × biochar interaction														
Cultivars	Biochar (m^3/fed.)													
Accent	0.00	69.83	37.90	107.73	68.73	3.18	0.306	3.10	0.243	309.3	19.7	17.7	18.0	364.3
	1.25	85.23	46.57	131.80	75.53	3.45	0.324	3.33	0.284	325.7	21.0	19.0	19.0	328.5
	2.50	105.50	51.30	156.80	81.33	3.68	0.340	3.59	0.295	342.7	24.0	22.0	21.0	295.5
	5.00	114.37	56.67	171.03	84.50	3.83	0.379	3.81	0.342	360.7	26.7	20.0	20.0	269.9
Cara	0.00	81.27	42.27	123.53	70.23	3.38	0.321	3.25	0.272	322.0	20.3	19.7	18.3	367.6
	1.25	99.20	47.23	146.43	77.87	3.58	0.334	3.47	0.306	339.3	22.3	20.3	22.3	342.4
	2.50	107.23	52.70	159.93	83.27	3.77	0.365	3.78	0.333	352.0	26.0	27.3	25.3	303.6
	5.00	118.23	59.37	177.60	85.63	3.86	0.388	3.93	0.362	366.7	28.0	29.3	26.0	272.7
Spunta	0.00	93.77	44.43	138.20	73.30	3.32	0.310	3.17	0.332	314.7	19.3	20.7	18.3	340.9
	1.25	102.77	49.47	152.23	80.43	3.50	0.330	3.42	0.290	332.0	22.3	20.3	20.0	348.2
	2.50	110.83	53.53	164.37	84.10	3.72	0.355	3.67	0.325	344.7	24.7	22.7	23.3	309.0
	5.00	122.63	60.70	183.33	87.60	3.93	0.384	3.84	0.344	364.0	27.7	25.7	23.3	282.8
L.S.D. at 0.05 level		12.09	7.28	16.94	4.40	0.55	0.015	0.56	0.056	5.3	6.1	4.0	3.5	42.2

N.S.: Not significant at 0.05 level probability and Feddan (fed.) = 4200 m^2 = 0.42 hectare.

TABLE 5. Effect of cultivars and biochar application on photosynthetic pigments and minerals content of leaf potato plants grown in sandy soil at 75 days after planting during 2017 season.

Treatments		Photosynthetic pigments Chlorophyll (mg/100 g FW)				Minerals content %				ppm.				Nitrate content (mg/kg DW)
		a	b	Total (a + b)	Caro-tenoides	N	P	K	Ca	Fe	Zn	Mn	Cu	
Cultivars														
Accent		98.48	67.76	166.24	78.26	3.34	0.285	4.49	0.284	349.9	23.3	27.9	20.8	292.7
Cara		101.26	70.26	171.53	80.58	3.56	0.301	4.83	0.296	359.1	25.2	30.8	22.8	293.1
Spunta		104.86	72.83	177.69	82.48	3.42	0.302	4.63	0.292	354.3	24.2	29.0	21.6	284.1
L.S.D. at 0.05 level		3.79	1.81	4.25	3.23	0.21	0.021	N.S.	0.012	N.S.	N.S.	1.6	1.7	N.S.
Biochar (m^3/fed.)														
0.00		88.66	58.07	146.72	71.14	3.19	0.259	3.94	0.255	333.1	20.2	24.8	17.9	332.7
1.25		97.03	66.97	164.00	79.00	3.36	0.277	4.49	0.282	345.1	22.9	27.8	20.8	299.1
2.50		104.81	73.52	178.33	83.35	3.52	0.316	4.89	0.304	359.3	25.9	30.1	22.9	276.1
5.00		115.64	82.59	198.24	88.28	3.70	0.330	5.27	0.322	380.2	27.8	34.3	25.3	252.0
L.S.D. at 0.05 level		4.00	3.16	5.36	3.05	0.19	0.024	1.33	0.015	17.8	4.0	2.1	2.4	19.9
Cultivars × biochar interaction														
Cultivars	Biochar (m^3/fed.)													
Accent	0.00	84.26	56.00	140.26	67.41	2.99	0.252	3.80	0.243	329.0	19.0	23.0	17.3	321.4
	1.25	95.25	64.78	160.03	77.17	3.26	0.270	4.30	0.275	340.7	21.3	27.3	19.7	306.9
	2.50	101.34	71.81	173.16	81.56	3.46	0.293	4.74	0.297	353.7	25.3	29.0	22.0	285.7
	5.00	113.07	78.47	191.53	86.90	3.65	0.323	5.13	0.320	376.3	27.3	32.3	24.3	256.8
Cara	0.00	88.86	58.33	147.19	71.34	3.49	0.264	4.08	0.268	336.3	21.3	26.3	18.7	349.3
	1.25	96.85	67.10	163.95	79.09	3.44	0.285	4.65	0.289	349.3	25.0	28.3	21.7	298.0
	2.50	104.13	73.35	177.48	83.48	3.58	0.315	5.08	0.311	365.7	26.3	32.0	24.0	270.3
	5.00	115.21	82.27	197.48	88.41	3.76	0.338	5.51	0.317	385.0	28.0	36.7	26.7	254.6
Spunta	0.00	92.84	59.87	152.71	74.66	3.08	0.260	3.93	0.255	334.0	20.3	25.0	17.7	327.3
	1.25	98.99	69.04	168.02	80.75	3.38	0.276	4.51	0.281	345.3	22.3	27.7	21.0	292.5
	2.50	108.95	75.38	184.34	85.00	3.51	0.341	4.85	0.303	358.7	26.0	29.3	22.7	272.3
	5.00	118.66	87.04	205.69	89.52	3.70	0.330	5.18	0.330	379.3	28.0	34.0	25.0	244.5
L.S.D. at 0.05 level		7.04	5.06	9.05	5.55	0.36	0.042	N.S.	0.026	37.61	N.S.	3.5	3.9	35.4

N.S.: Not significant at 0.05 level probability and Feddan (fed.) = 4200 m^2 = 0.42 hectare.

Yield and its components

There were no significant differences among the investigated potato cultivars, *i.e.* Accent, Cara and Spunta in tuber yield/plant, yield of grade 2 and total yield in both seasons, as well as yield of grade 1 and marketable yield in the first season (Tables 6 and 7). Spunta cv. gave the highest average tuber weight followed by Cara cv., whereas Accent cv. gave the lowest values of average tuber weight in both seasons. The increases in average tuber weight of potato cvs. Spunta and Cara may be due to that potato cvs. Spunta and Cara recorded the highest values of plant growth traits, whereas Accent cv. recorded the lowest values of plant growth traits (Tables 2 and 3). As for number of tubers per plant, Accent cv. recorded the maximum values, whereas Spunta cv. recorded the lowest values in both seasons. These results contradicted with those reported by Vakis (1990), who found that Spunta and Cara cvs. recorded the highest values of tuber yield, whereas Accent cv. recorded the minimum values.

Number of tubers/plant, tuber yield/plant, yield of grade 2 and 3, marketable yield and total yield/fed. were significantly increased with increasing biochar application rates up to 5 m^3/fed. in both seasons (Tables 6 and 7). The increases in total yield were about 12.27 and 14% for biochar application rate at 1.25 m^3/fed., 21.04 and 22.26% for biochar rate at 2.5 m^3/fed. while it were 28.48 and 35.05% for biochar application rate at 5 m^3/fed. over the control (without biochar) in the first and second seasons, respectively. Treating potato plants with biochar at different rates had no significant effect on average tuber weight in both seasons. The simulative effect of biochar at 5 m^3/fed. on total yield/fed. may be due to that biochar at 5 m^3/fed. increased the morphological traits (Table 2), total dry weight (Table 3), photosynthetic pigments and mineral contents (Tables 4 and 5), number of tubers/ plant, tuber yield/plant and yield of grades 1 and 3 (Tables 6 and 7). In this respect, Lehmann et al. (2006) found that biochar addition can improve plant productivity directly because of its nutrient content and release characteristics, or indirectly, through improved nutrient retention. Additionally, the potential of biochar to improve the water availability and retention properties of soil (Jha et al., 2010, Jeffery et al., 2011, Sun and Lu, 2014). Also, Akhtar et al. (2014) indicated that addition of biochar increased the soil moisture contents, which consequently improved yield of tomato fruits. Furthermore, Nair et al. (2014) stated that the increases in crop yields of potato cv. Atlantic have been attributed to better water holding capacity, higher cation exchange capacity, increased nutrient retention, and the ability of biochar to reduce bulk density. Biochar could be a valuable tool for management of soils that are either degraded or have poor nutrient status, however, it would take time to observe significant changes in soil and crop attributes after biochar addition. These results agree with those reported by Lehman et al. (2006, 2009), Asai et al. (2009), Dou et al. (2012) and Carter et al. (2013).

The interaction between cultivars and biochar rates had a significant effect on yield and its components, except yield of grade 1 in the first season (Tables 6 and 7). In both seasons, generally, potato cvs. Accent, Cara and Spunta grown in sandy soil with biochar at a rate of 2.5 or 5 m^3/fed. significantly increased tuber yield/plant, yield of grade 2, marketable yield and total yield/fed. While, Cara and Spunta yield/fed. (17.091 and 16.950 ton/fed. for cv. Cara and 17.217 and 17.236 ton/fed. for cv. Spunta in the first and second seasons, respectively).The increases in total yield/fed. were about 32.42 and 42.19% for Accent cv., 35 and 42.17%, for Cara cv. and 36 and 44.57% for Spunta cv. when growing them with biochar adding at a rate of 5 m^3/fed. which were over the Accent cv. grown without biochar (control) in the first and second seasons, respectively. As for yield of grade 3 of Cara, Spunta and Accent cvs. grown without biochar (control) markedly gave the highest values of potato grade 3 yield of in both seasons. These results agree with those reported by Nair et al. (2014) who found that yield of potato cv. Atlantic increased with increasing biochar.

TABLE 6. Effect of cultivars and biochar application on yield and its components of potato plants grown in sandy soil during 2016 season.

Treatments		Average tuber weight (g)	Tubers/plant		Yield (ton/fed.)					Relative total yield (%)
			Number	Weight (kg)	Grade 1	Grade 2	Grade 3	Marketable	Total	
Cultivars										
Accent		95.58	7.11	0.680	2.067	9.882	2.961	11.949	14.910	100.00
Cara		111.57	6.31	0.704	1.808	10.603	3.052	12.411	15.463	103.71
Spunta		120.45	5.92	0.713	1.907	10.347	3.261	12.254	15.515	104.06
L.S.D. at 0.05 level		18.98	0.89	N.S.	0.195	N.S.	0.162	N.S.	N.S.	-
Biochar (m^3/fed.)										
0.00		104.56	5.93	0.620	2.279	8.556	2.414	10.835	13.249	100.00
1.25		107.23	6.37	0.683	1.860	10.031	2.983	11.891	14.874	112.27
2.50		112.34	6.52	0.732	1.856	10.910	3.270	12.766	16.036	121.04
5.00		112.67	6.96	0.784	1.713	11.612	3.698	13.325	17.023	128.48
L.S.D. at 0.05 level		N.S.	0.62	0.064	0.439	1.187	0.230	1.242	1.398	-
Cultivars × biochar interaction										
Cultivars	Biochar (m^3/fed.)									
Accent	0.00	84.73	6.89	0.584	2.425	7.967	2.268	10.392	12.660	100.00
	1.25	92.97	7.00	0.651	1.951	9.493	2.895	11.444	14.339	113.26
	2.50	101.93	7.11	0.725	1.975	10.692	3.211	12.667	15.878	125.42
	5.00	102.70	7.45	0.765	1.918	11.375	3.468	13.293	16.761	132.42
Cara	0.00	108.03	5.67	0.613	2.159	8.991	2.280	11.150	13.430	106.39
	1.25	108.87	6.33	0.689	1.775	10.407	2.944	12.182	15.126	119.48
	2.50	116.77	6.33	0.739	1.781	11.177	3.245	12.958	16.203	127.99
	5.00	112.60	6.89	0.779	1.516	11.837	3.738	13.353	17.091	135.00
Spunta	0.00	120.90	5.22	0.631	2.255	8.711	2.694	10.966	13.660	107.90
	1.25	119.87	5.78	0.693	1.843	10.194	3.110	12.037	15.147	119.64
	2.50	119.30	6.11	0.729	1.824	10.861	3.353	12.687	16.038	126.68
	5.00	121.73	6.56	0.799	1.705	11.624	3.888	13.329	17.217	136.00
L.S.D. at 0.05 level		27.08	1.27	0.108	0.685	1.988	0.380	2.098	2.372	-

N.S.: Not significant at 0.05 level probability and Feddan (fed.) = 4200 m^2 = 0.42 hectare.

TABLE 7. Effect of cultivars and biochar application on yield and its components of potato plants grown in sandy soil during 2017 season.

Treatments		Average tuber weight (g)	Tubers/plant		Yield (ton/fed.)					Relative total yield (%)
			Number	Weight (kg)	Grade 1	Grade 2	Grade 3	Marketable	Total	
Cultivars										
Accent		104.02	6.307	0.656	2.050	9.963	2.354	12.013	14.367	100.00
Cara		121.18	5.750	0.697	1.949	10.654	2.554	12.603	15.157	105.50
Spunta		126.70	5.472	0.693	2.010	10.335	2.746	12.345	15.091	105.04
L.S.D. at 0.05 level		6.39	0.170	N.S.	N.S.	N.S.	0.095	0.677	N.S.	-
Biochar (m^3/fed.)										
0.00		117.50	4.93	0.579	2.455	8.325	1.841	10.780	12.621	100.00
1.25		118.33	5.59	0.661	2.073	9.977	2.338	12.050	14.388	114.00
2.50		116.09	6.15	0.714	1.777	10.900	2.754	12.677	15.431	122.26
5.00		117.28	6.70	0.786	1.706	12.066	3.273	13.772	17.045	135.05
L.S.D. at 0.05 level		N.S.	0.17	0.068	0.724	0.971	0.194	1.064	1.499	-
Cultivars × biochar interaction										
Cultivars	Biochar (m^3/fed.)									
Accent	0.00	101.13	5.33	0.539	2.620	7.636	1.666	10.256	11.922	100.00
	1.25	103.00	6.11	0.629	2.207	9.507	2.159	11.714	13.873	116.36
	2.50	101.67	6.67	0.678	1.592	10.565	2.564	12.157	14.721	123.48
	5.00	110.27	7.11	0.784	1.780	12.143	3.029	13.923	16.952	142.19
Cara	0.00	122.13	4.89	0.597	2.349	8.926	1.797	11.275	13.072	109.65
	1.25	123.83	5.44	0.674	1.974	10.315	2.376	12.289	14.665	122.92
	2.50	122.30	6.00	0.734	1.856	11.320	2.765	13.176	15.941	133.71
	5.00	116.47	6.67	0.777	1.617	12.054	3.279	13.671	16.950	142.17
Spunta	0.00	129.23	4.55	0.588	2.397	8.412	2.060	10.809	12.869	107.94
	1.25	128.17	5.22	0.669	2.038	10.110	2.479	12.148	14.627	122.69
	2.50	124.30	5.78	0.718	1.884	10.816	2.932	12.700	15.633	131.13
	5.00	125.10	6.33	0.792	1.722	12.001	3.512	13.723	17.235	144.57
L.S.D. at 0.05 level		18.52	0.31	0.110	N.S.	1.607	0.305	1.726	2.413	-

N.S.: Not significant at 0.05 level probability and Feddan (fed.) = 4200 m^2 = 0.42 hectare.

Tuber quality

There were significant differences among Accent, Cara and Spunta cultivars in N, K, total protein, total carbohydrates, starch, nitrate and dry matter (DM) contents (Tables 8 and 9). Potato cvs. Cara and Spunta potato plants recorded the maximum N, K, total carbohydrate and DM contents (%) in tubers; whereas Spunta cv. recorded the highest tubers starch content percentage. Regarding nitrate content in tubers, Accent cv. recorded the lowest values, whereas Spunta cv. recorded the highest value. There were no significant differences among the three tested potato cultivars in total protein in the first season and P contents (%) in the secon season, as well as specific gravity (SG) of potato tubers in both seasons.

Data presented in Tables (8 and 9) show that N, P, K, total protein, total carbohydrate, starch and dry matter contents (%) in tubers significantly increased with increasing biochar application rates up to 5 m^3/fed., with no significant differences with 2.5 m^3/fed. with respect to N, total protein, total carbohydrate, starch and DM (%). Biochar at 2.5 m^3/fed. increased contents (%) of N, total protein, total carbohydrate, starch and DM, whereas biochar at 5 m^3/fed. increased P and K contents (%) in potato tubers.

Concerning nitrate content in tubers, it was significantly decreased with increasing biochar application rates up to 5 m^3/fed. Biochar at 5 m^3/fed. gave the lowest values of nitrate in tubers. While, biochar application rates had no significant effect on DM content (%) in the first season and on the specific gravity of tubers in both seasons. In this respect, Akhtar et al. (2014), found that biochar addition improved quality of tomato fruits.

Feasibility study

Adding biochar to the field of potato plants (Cara and Spunta) cultivars grown in sandy soil amended with biochar at 2.5 or 5 m^3/fed. markedly increased gross and net return, as well as cost benefit ratio in the both studied seasons (Table 10). Treated Cara plants with biochar at a rate of 5 m^3/fed. gave the highest values of gross and net return, as well as cost benefits ratio followed by treating Spunta plants with 5 m^3/fed. On the other hand, treating Accent cv. with different biochar application rates gave the lowest values of gross and net return, as well as cost benefit ratio. These results may be due to that Cara and Spunta potato with biochar at 2.5 or 5 m^3/fed. gave the highest values of total yield (Tables 6 and 7). In this respect, Dou et al. (2012) revealed that biochar could increase yield, sugar content and appearance quality of sweet potato, which was conducive to bringing more economic profits for farmers and improving food safety through using organic fertilizers, and finally promoting sustainable crop production. Moreover, biochar improves fertility of soil and nutrient and water use efficiencies (Hale, 2013).

Conclusion and Recommendations

Our current investigation found that adding biochar to the field of potato plants (cultivars, Cara, Spunta or Accent), which were grown in sandy soil (El-Kassasein region, Ismailia Governorate, Egypt) improved plant growth, plant chemical compositions, tuber yield and its components with good tubers quality. Additionally, using biochar markedly reduced the costs and increase the net return of potato production and kept the environment less polluted.

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Conflicts of interest

The authors agree that there is no conflict of interest to any destinations or personal.

TABLE 8. Effect of cultivars and biochar application on tuber quality of potato plants grown in sandy soil at harvest time during 2016 season.

Treatments		Minerals content (%)			Total (%)		Starch (%)	Nitrate content (mg/kg DW)	Dry matter (%)	Specific gravity
		N	P	K	Protein	Carbo-hydrates				
Cultivars										
Accent		2.14	0.273	2.68	13.38	70.41	48.49	260.0	15.58	1.053
Cara		2.36	0.293	3.02	14.75	80.43	59.22	299.0	18.73	1.074
Spunta		2.29	0.283	2.93	14.31	81.24	65.24	303.3	19.87	1.079
L.S.D. at 0.05 level		1.25	0.011	0.25	N.S.	4.53	1.81	25.6	1.12	N.S.
Biochar (m^3/fed.)										
	0.00	1.94	0.239	2.37	12.13	72.81	56.04	344.2	17.38	1.060
	1.25	2.20	0.273	2.72	13.75	75.48	56.72	326.1	17.95	1.069
	2.50	2.52	0.297	2.93	15.75	80.00	58.53	264.2	18.24	1.071
	5.00	2.49	0.322	3.46	15.56	81.12	59.31	215.2	18.67	1.074
L.S.D. at 0.05 level		0.51	0.022	0.19	2.21	3.22	2.86	28.2	N.S.	N.S.
Cultivars × biochar interaction										
Cultivars	Biochar (m^3/fed.)									
Accent	0.00	1.83	0.220	2.17	11.44	60.84	46.80	304.6	14.42	1.033
	1.25	2.13	0.268	2.60	13.31	66.15	47.25	302.9	15.37	1.057
	2.50	2.29	0.287	2.84	14.31	75.92	49.50	250.2	16.01	1.060
	5.00	2.29	0.316	3.10	14.31	78.72	50.40	182.1	16.52	1.063
Cara	0.00	2.03	0.256	2.54	12.69	77.59	57.48	357.6	18.22	1.071
	1.25	2.26	0.280	2.82	14.13	80.10	57.79	343.1	18.65	1.073
	2.50	2.55	0.307	3.00	15.94	81.45	60.33	265.8	18.76	1.074
	5.00	2.59	0.329	3.67	16.19	82.51	61.28	229.6	19.30	1.077
Spunta	0.00	1.95	0.242	2.41	12.19	79.99	63.84	370.3	19.50	1.077
	1.25	2.22	0.271	2.73	12.88	80.20	65.12	332.4	19.82	1.078
	2.50	2.72	0.296	2.96	17.00	82.64	65.76	276.5	19.96	1.079
	5.00	2.58	0.322	3.63	16.13	82.12	66.24	234.0	20.20	1.081
L.S.D. at 0.05 level		N.S.	0.035	0.38	N.S.	6.56	4.64	49.1	2.24	N.S.

N.S.: Not significant at 0.05 level probability and Feddan (fed.) = 4200 m^2 = 0.42 hectare.

TABLE 9. Effect of cultivars and biochar application on tuber quality of potato plants grown in sandy soil at harvest time during 2017 season.

Treatments		Minerals content (%)			Total (%)		Starch (%)	Nitrate content (mg/kg DW)	Dry matter (%)	Specific gravity
		N	P	K	Protein	Carbohydrates				
Cultivars										
Accent		2.34	0.268	2.63	14.63	68.08	48.86	243.9	15.58	1.054
Cara		2.56	0.282	2.82	16.00	79.10	59.73	247.4	18.67	1.074
Spunta		2.42	0.272	2.74	15.13	81.27	66.03	253.1	19.73	1.079
L.S.D. at 0.05 level		0.13	N.S.	0.16	0.83	2.26	2.02	4.9	1.24	N.S.
Biochar (m^3/fed.)										
0.00		2.03	0.236	2.33	12.69	70.97	55.30	266.3	17.09	1.058
1.25		2.37	0.271	2.45	14.81	75.80	57.33	251.3	17.86	1.069
2.50		2.61	0.275	2.84	16.31	78.03	59.63	241.0	18.16	1.073
5.00		2.75	0.313	3.29	17.19	79.79	60.57	233.9	18.85	1.075
L.S.D. at 0.05 level		0.17	0.051	0.36	1.05	3.85	2.65	8.6	1.03	N.S.
Cultivars × biochar interaction										
Cultivars	Biochar (m^3/fed.)									
Accent	0.00	1.88	0.227	2.31	11.75	59.67	45.90	257.7	14.08	1.030
	1.25	2.24	0.253	2.39	14.00	68.04	48.75	248.4	15.38	1.056
	2.50	2.55	0.286	2.70	15.94	70.90	49.95	238.5	16.13	1.062
	5.00	2.70	0.306	3.12	16.88	73.71	50.85	230.8	16.71	1.066
Cara	0.00	2.18	0.245	2.37	13.63	73.99	56.05	264.6	18.00	1.070
	1.25	2.57	0.276	2.53	16.06	78.88	58.43	251.6	18.43	1.072
	2.50	2.66	0.282	2.94	16.63	81.15	62.23	240.0	18.53	1.076
	5.00	2.81	0.325	3.42	17.56	82.39	62.23	233.5	19.71	1.076
Spunta	0.00	2.02	0.235	2.32	12.63	79.25	63.96	276.5	19.20	1.074
	1.25	2.29	0.287	2.43	14.31	80.48	64.80	253.9	19.76	1.078
	2.50	2.63	0.257	2.89	16.44	82.05	66.72	244.5	19.82	1.080
	5.00	2.72	0.308	3.33	17.00	83.28	68.64	237.4	20.12	1.082
L.S.D. at 0.05 level		0.28	N.S.	0.57	1.76	6.18	4.44	13.7	1.96	N.S.

N.S.: Not significant at 0.05 level probability and Feddan (fed.) = 4200 m^2 = 0.42 hectare.

TABLE 10. Feasibility study for the effect of the interactions between cultivars and biochar application on potato plants grown under sandy soil conditions.

Treatments		Cost (L.E./fed)			Total/ Yield (ton/fed.)	Price (L.E./ ton)	L.E./fed.		Benefits Ratio
Cultivars fed.)	Biochar (m^3/	Treatment	Production	Total			Gross Return	Net Return	
2016 Season									
Accent	0.00	4500	10000	14500	12.660	3250	41143	26643	2.84
	1.25	4538	10000	14538	14.339	3250	46602	32064	3.20
	2.50	4575	10000	14575	15.878	3250	51603	37029	3.54
	5.00	4650	10000	14650	16.761	3250	54474	39824	3.72
Cara	0.00	5500	10000	15500	13.430	4000	53719	38219	3.47
	1.25	5538	10000	15538	15.126	4000	60501	44964	3.89
	2.50	5575	10000	15575	16.203	4000	64811	49236	4.16
	5.00	5650	10000	15650	17.091	4000	68365	52715	4.37
Spunta	0.00	5000	10000	15000	13.660	3750	51223	36223	3.43
	1.25	5038	10000	15038	15.147	3750	56799	41761	3.78
	2.50	5075	10000	15075	16.038	3750	60145	45070	3.99
	5.00	5150	10000	15150	17.217	3750	64564	49414	4.26
L.S.D. at 0.05 level		-	-	-	2.372	-	8661	8661	0.57
2017 Season									
Accent	0.00	5000	11500	16500	11.922	3750	44708	28208	1.71
	1.25	5038	11500	16538	13.873	3750	52021	35484	2.14
	2.50	5075	11500	16575	14.721	3750	55204	38629	2.33
	5.00	5150	11500	16650	16.952	3750	63573	46923	2.82
Cara	0.00	6000	11500	17500	13.072	4500	58826	41326	2.36
	1.25	6038	11500	17538	14.665	4500	65991	48454	2.76
	2.50	6075	11500	17575	15.941	4500	71733	54158	3.08
	5.00	6150	11500	17650	16.950	4500	76274	58623	3.32
Spunta	0.00	5500	11500	17000	12.869	4250	54693	37693	2.22
	1.25	5538	11500	17038	14.627	4250	62165	45127	2.65
	2.50	5575	11500	17075	15.633	4250	66439	49364	2.89
	5.00	5650	11500	17150	17.235	4250	73252	56102	3.27
L.S.D. at 0.05 level		-	-	-	2.413		9629	9629	0.57

Feddan (fed.) = 4200 m^2 = 0.42 hectare.

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تـأثير إضـافة الفحـم النبـاتي على إنتاجيـة، وجـودة درنـات بعض أصنـاف البطـاطس تحـت ظـروف الأرض الرمليـة

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أجريت هذه الدراسة خلال الموسمين الصيفيين لعامى ٢٠١٦ و٢٠١٧ لدراسة تاثير إضافة الفحم النباتي بمعدل: ٠، ١,٢٥، ٢,٥ و٥م٣/الفدان على النمو والإنتاجية وجودة الدرنات لبعض أصناف البطاطس (أكسنت، كارا، سبونتا) النامية تحت ظروف الأرض الرملية. حيث سجل الصنفان كارا وسبونتا أعلي القيم لصفات النمو ومحتوي الأوراق من عنصرالكالسيوم والمنجنيز والنحاس وكذلك محصول الدرنات وجودتها. وسجل صنف كارا أعلى القيم للوزن الجاف لأجزاء النبات المختلفة. أما صنف سبونتا فقد سجل أعلي القيم من حيث محتوى صبغات التمثيل الضوئى في الأوراق، ومحتوي النشا في الدرنات. بينما سجل الصنف أكسنت أقل القيم للصفات المذكورة سابقا وإنخفض محتوى درناته من النترات. أما زيادة معدل إضافة الفحم النباتي حتى ٥م٣/الفدان، فقد سجلت أعلي القيم لصفات النمو الخضري ومحتوي الأوراق من عناصر(النيتروجين والفوسفور والبوتاسيوم والكالسيوم والحديد والزنك والمنجنيز والنحاس)، وكذلك المحصول ومكوناته وجودته. إن معاملة نباتات صنف كارا أوسبونتا بالفحم النباتي زادت من نمو النباتات ومحتوى الأوراق من الكلورفيل والعناصر الكيميائية. معاملة الأصناف الثلاث بالفحم النباتي بمعدل ٢,٥ أو ٥ م٣/الفدان سجلت أدني القيم لمحتوي النترات في الأوراق وأعلى القيم من محصول الدرنات ومكوناته. وكذلك فإن إضافة الفحم النباتي للصنفين كارا أو سبونتا زادت من نسبة محتوى الكربوهيدرات والنشا وخفضت من محتوي النترات في الدرنات. أخيرا فإن إضافه الفحم النباتي إلى نباتات البطاطس المزروعة في الأرض الرملية قد حسن من نمو النبات ومحتواه الكيميائي والمحصول ومكوناته وأنتج نوعية جيدة من الدرنات وخفض تكاليف الإنتاج مما زاد من صافي العائد لزراعة البطاطس مع المحافظة على البيئة من التلوث.