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MANAGEMENT STRATEGY OF BIOCHAR AND COMPOST FOR IMPROVING THE PRODUCTIVITY OF VALENCIA ORANGE GROWN ON SANDY SOIL

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Abstract

Temperature regime is an important environmental factor that could affect the growth and productivity of citrus trees. Therefore, the application of biochar is considered as a new way to improve both fertility and water holding capacity in the sandy soil, hence, reduce high temperature stress and its detrimental to trees and increase the production. This study was carried out during two successive growing seasons (2017 and 2018) on Valencia orange trees grown in the National Research Centre farm for research and production in Al- Nubaria region, Al- Behira Governorate, Egypt using biochar and compost, all were applied either in one application in the winter '1' (the first week of January) or in two equal applications in the winter and the summer '1-2' (the first week of January and the first week of August). We can recommend adding biochar '1' once to trees as they gave the best vegetative growth represented by the shoot length, number of formed leaves and their content of chlorophyll. It also gave the highest leaf content of phosphorous, magnesium, manganese and zinc, as well as the addition of compost '1' once was in the second rank. Such, the yield and its components were superior with the addition of compost '1-2' once or twice, followed by biochar '1' once. Also, most of the fruit characteristics were not affected by these additions, especially in the first season

Keywords : Biochar, compost, Valencia orange, growth, nutrients status, yield, fruit quality.

Introduction

One of the most important environmental factors that could affect the growth and productivity of citrus trees is the temperature regime, however, temperature sensitive crops include perennial crops such as almonds, grapes, berries, citrus and stone fruits (Lobell and Field, 2011). This is due to the negative impacts of stress upon photosynthesis and crop water status. Different citrus varieties have varied responses to heat stresses which can show negative responses to heat/light as abortion of flower and fruit, trees shut down, water stress, photosynthesis reduction, smaller fruit and lower yields and poorer quality of fruit (Pope, 2012 and Beppu and Kataoka, 2011).

Biochar "charcoal" is produced of thermal degradation of organic materials in the absence of air (Lehmann and Joseph, 2009). Charcoal is the dark residue consisting of carbon, and the remaining ash, obtained by removing water and other volatile constituents from vegetation substances (Laird, 2008). It is usually produced by pyrolysis at temperatures from 300 to 600 °C (Rajkovich *et al.,* 2012). When it is used, it changes soil biological conditions in terms of the quality and quantity of soil microorganisms (Kim *et al.,* 2004). Biochar can act as a soil conditioner enhancing plant growth by supplying nutrients and improving soil physical and biological properties (Lehmann and Rondon, 2005), and these changes can lead to differences in plants growth and productivity (Kim *et al.,* 2004). Application of charcoal to soils is hypothesized to increase available water, build soil organic matter, enhance nutrient cycling, and reduce leaching of pesticides and nutrients to surface and ground water (Novak *et al.,* 2009 and Brookes *et al.,* 2010). Leach *et al.* (2010) documented that application of biochar to the soil increases agricultural productivity without or with much reduced applications of inorganic fertilizer.

The application of organic materials to sandy soil as a source of organic matter are recognized ways of improving their physical, chemical as well as their biological properties (Zhou *et al.,* 2001). Also, adult citrus trees should have annual application of 20-25 kg/tree stable manure with 1-2 kg/tree rapeseed cake manure (Liang Zhi and Peng, 1998). The use of organic waste materials as nitrogen "N" source is considered as the best management for N fertilization practice, because organic N is released to the plant more gradually than water soluble mineral N fertilizers (Obreza and Ozores, 2000). Concerning date of organic manures application for maintaining adequate mineral content in leaves during growth activities of the tree for having economical yield, organic manure could be added either once application in winter or two equal applications in winter and summer (Abd El-Naby *et al.,* 2004).

The aim of this work was to evaluate the effect of addition of biochar comparing with compost and their application date on growth, nutrients status, yield and fruit quality of Valencia orange trees grown under sandy soil.

Materials and Methods

Plant material

Experiment was carried out at the Research and Production Station, National Research Centre, El-Nubaria region, El-Behira Governorate, Egypt during 2017 and 2018 seasons on Valencia orange (*Citrus sinensis* Osbeck) trees, budded on volkamer lemon rootstock (*C. volkameriana,* L), were about twelve years old, and in healthy and nearly uniform vigor planted in a system of 3.5 x 5 meters and irrigated by drip irrigation system.

Organic fertilizer sources and application dates

Organic fertilizers as Compost and Biochar "Charcoal" were used to reduce the impact of heat stress on the sandy soil by maintain moisture and supply necessary organic matter for growth and improve productivity and quality. Those were in a form:

1. Compost was produced from many plant wastes by commercial company. 2. Biochar "charcoal or biomass-derived black carbon" was produced by another commercial company. 3. The trees received no compost or biochar reserved as control.

Addition of each was at a rate of (4 tons/fed). All were broadcasted and incorporated into the root zone of the tree canopy under the drippers at the same N rate recommended of basal dressing of fertilizer as recommended from national campaign for improving citrus productivity in Egypt, all were applied either in one application in the winter (the first week of January) or in two equal applications in the winter and the summer (the first week of January and the first week of August). Its chemical properties were determined before soil application during two successive seasons and were shown in (Table 1). Also, the soil texture class of the farm was sandy which, sand (92.6 %), silt (2.8 %), clay (4.6 %) and $CaCO_3$ was (1.2 %). Some chemical characteristics of the soil at the beginning of the experiment are listed in Table (l).

Table 1 : Analytical data of Soil, biochar, and compost

Character	Soil	Biochar		Compost	
	Available macronutrients (mg/100 g)	Total macronutrients (%)			
		1st season	2nd season	1st season	2nd season
Total N	14.8	1.15	1.05	1.41	1.32
Available P	1.56	0.12	0.1	0.13	0.16
Ca	286	2.35	2.75	1.52	1.4
Mg	29.2	0.11	0.15	0.72	0.8
Na	29.6	0.47	0.38	1.94	1.82
K	9.34	1.08	0.79	1.29	1.1
	Available micronutrients (mg/100 g)	Total micronutrients (mg/kg)			
Fe	16.4	372	399	2800	2720
Mn	4.8	3.03	2.8	5.72	4.84
Zn	0.9	26.5	36.8	57	48
Cu	0.4	96	53.9	20	18
Total carbon		86.9	84.1	40	36.8
Moisture		10.86	10.4	21.3	21.2
E C (ds/m) 1:2.5	0.41	2.49	1.86	6.44	6.8
pH 1:2.5	8.25	8.99	8.74	7.74	7.92
O.M.%	0.48	1.98	2.11	11.36	10.7

The trees were subjected to the same horticultural practices with fertigation system. A complete randomized block design was adopted in this experiment with five treatments, where each treatment contained three replicates with one tree each.

The following five treatments were included in this experiment:

T1- Compost 1 = applied in one application in the winter (the first week of January)

T2- Compost 2 = applied in two equal applications in the winter and the summer (the first week of January and the first week of August).

T3- Biochar 1 = applied in one application in the winter (the first week of January)

T4- Biochar 2 = applied in two equal applications in the winter and the summer (the first week of January and the first week of August).

T5- Control = The trees received no compost or biochar.

Measurements:

Growth and yields: in early September, leaf area was measured using the formula of 0.608 constant x (maximum leaf length x maximum leaf breadth) according to Shrestha and Balakrishnan (1985). Number of shoots/one-meter branch, Number of leaves/shoot and shoot length (cm) were measured. Chlorophyll content was determined as CCI (Chlorophyll Content Index) using Chlorophyll content Meter 003109 (CCM-200 plus Opti -Sciences). Canopy volume of trees was measured in early December which tree shape was considered as a one-half of a probate sphere (volume = 4/6 x π x height x radius^2 "which π = 22/7") as described by Roose *et al.,* (1989). At commercial harvest in early April, yield as weight (Kg) and number of fruits per tree was recorded. Cropping efficiency was calculated by dividing the fruit yield weight by the canopy volume according to Whitney *et al.,* (1995).

Leaf mineral composition: leaf samples were collected in early September and were mature fully expanded from non-fruiting non flushing spring cycle growth (5 months old) according to Jones and Embleton (1960), then washed, dried at 70 °C until a constant weight and digested using an acid mixture consisting of nitric, perchloric and sulfuric acids in the ratio of 8:1:1 (v/v), respectively according to Chapman and Pratt (1978). Nitrogen was measured by semi-micro Kjeldahl method of Plummer (1978). Phosphorus was determined using a spectrophotometer at 882-OVV by the method outlined by Jackson (1973). Potassium, calcium and sodium were determined by a flame photometer "Jenway PFP7". Magnesium, iron, manganese, zinc and copper were determined using atomic absorption Spectrophotometer "Perkin Elmer 1100" (Cottanie *et al.,* 1982). These measurements were performed in the Agricultural Services Unit and Laboratory Analysis of Research Project (Micronutrients and Other Plant Nutrition Problems in Egypt) in NRC.

Fruit quality: ten fruits were randomly sampled per each tree for determination of weight, diameter, peel thickness and then from the juice, total soluble solids percentage (TSS Brix %) determined by Carl Zeiss hand refractometer; total acidity as anhydrous citric acid % and vitamin C was expressed as mg ascorbic acid per 100 ml juice according to A.O.A.C.(1995).

Statistical analysis: The data obtained in each season were analyzed by ANOVA according to Snedecor and Cochran (1982). Means were separated by Duncan (1955) and multiple range test using a significance level of $P<0.05$.

Results and Discussion

1. Effect of compost and biochar on vegetative growth characteristics and chlorophyll content

Table (2) shows the effect of adding different organic fertilizer sources and its application dates "biochar and compost" on the characteristics of the vegetative growth of Valencia orange trees, where it was found that adding biochar '1' once to trees at the winter gave the longest shoot and the most number of leaves on the shoot, which had higher chlorophyll content, this was true during the two seasons of the study. It also led to the formation of the largest number of shoots/one meter branch with maximum leaf area in the second season only, compared to the other additions. On the other hand, there were no significant differences between all compost and biochar additions once or twice on the leaf content of chlorophyll compared to the control in the first season, but in the second season, the addition of biochar '1' once was with similar effect of compost '1 or 2' once or twice. The use of organic residues not only increased physical (porosity, structure and water-holding capacity) and chemical properties of soil, but also increased mineral composition, which is essential for proper development of plant. This could be due to the positive impact of biochar on plant growth (Kolton *et al.,* 2011). Moreover, the indirect nutrient value of biochar is its ability to retain nutrients in the soil and, therefore, to reduce leaching losses, resulting in increased nutrient uptake by plants and production increment (Glaser *et al.,* 2002). Also, it can act as a soil conditioner and enhance the growth of the plant which improve soil fertility and sequester carbon for reduction of carbon mitigation to mitigate climate change (Lehmann and Rondon, 2005).

2. Effect of compost and biochar on leaf minerals content

It is clear from Table (3) that adding biochar '1' once to Valencia orange trees improved the leaf content of phosphorus and magnesium in the two seasons of study. The content of magnesium in the control tree leaf was at the same level, while adding once or twice of compost '1-2' improved the nitrogen in the two seasons of study and potassium in the first season, as well as phosphorous and calcium in the second season. We can notice that the best level of potassium was in the second season with the twice addition of either compost '2' or biochar '2' and control. Also, the best magnesium content was in the first season with the addition of compost '2' twice or biochar '1' once or the control. These results are in agreement with those obtained by Glaser (2007) who stated that, since biochar is produced from organic materials, it inherently contains nutrients that are found in its mineral fraction. Therefore, the addition of biochar to soil adds free exchangeable bases such as K, Ca, and Mg to occupy the soil-exchange sites, thus resulting in an increase in soil pH, and readily supplying plant nutrients for growth. Chan and Xu (2009) reported that, although the soil-biochar mixtures increasing C:N ratios, it is important to note that the total elemental contents of N, which is organically bound, does not reveal the definite plant available N. This could be due to the positive role of biochar in improving the physical properties of soil, plant growth and dry matter accumulation so that improvement in quality parameters and increasing the uptake of most nutrients. The efficiency of application of each of compost or biochar gave the highest values in N, P, K. In this regard, an obvious positive effect is its nutrient value, supplied either directly by providing nutrients to trees or indirectly by improving soil quality, with consequent improvement in the efficiency of fertilizer use.

Table (4) shows that the biochar '1' added once to Valencia orange trees helped to create leaves which its content from manganese and zinc is higher in the two seasons of study, and that the addition of compost '1' once in the second season led to an increase in the percentage of iron, manganese, zinc and sodium in the leaf, while adding compost '2' twice in the first season, also, gave higher leaf copper and sodium content as they were on the same direction with control. As for adding two batches of biochar '2' gave leaves high iron content in the first season. Also, leaf zinc content in the second season of all treatments showed approximately the same average. Organic fertilizers not only increased physical (porosity, structure and water-holding capacity) and chemical properties of soil but also increased mineral composition, which is essential for proper development of plant. In this respect, Glaser *et al.* (2002) and Brookes *et al.* (2010) found that the application of charcoal increases bio available water, builds soil organic matter, enhances nutrient cycling, lower bulk density, acts as a liming agent, and reduces leaching of nutrients to ground water.

3. Effect of compost and biochar on yield and its components

In Table (5), all biochar and compost additions resulted in increasing the yield and its components from the number of fruits and its weight compared to the control in the two seasons (2017-2018), where the addition of compost '1' once gave the highest yield, which is attributed to the production of a greater number of fruits, and also the yield resulting from the addition of the compost '2' twice was on the same direction , but it is attributed to an increase in the average weight of the fruit. The yield obtained from the addition of biochar '1-2' once or twice was in the second rank. This yield is attributed to an increase in the average weight of the fruit, and this was true in the two seasons of the study. On the other hand, the largest volume of trees was resulted from the addition of compost '1' once in the first season and from biochar '2' twice in the second season. The crop efficiency was the highest when compost '2' was added twice in the first season, and biochar '1' once in the second season where all treatments were superior compared to the control trees in the two seasons. This increase in yield could be due to the ability of charcoal for improving soil condition by increasing water holding capacity and number of useful soil microorganisms (Jeffery *et al.,* 2011). So, when biochar improves crop response, it can be attributed to direct effects via biochar-supplied nutrients (Silber *et al.,* 2010), and to several other indirect effects, including: high nutrient retention; improvements in soil pH, high soil cation exchange capacity (Yamata *et al.,* 2006), effects on P (Phosphorus) and S (Sulfur) transformations and turnover, neutralization of phytotoxic compounds in the soil and alteration of soil microbial populations and functions (Kolton *et al.,* 2011). The results from the current study agree with positive yield values when either (Chan *et al.,* 2007; Kimetu *et al.,* 2008 and Vaccari *et al.,* 2011) added biochar doses or (Abd El-Naby and El Sonbaty,2016) used organic manure additions.

4. Effect of compost and biochar on fruit characteristics.

From the data in Table (6) it is clear that when Valencia orange trees were subjected to each of the addition of biochar '1' in the winter during the two seasons of the study or of the addition of compost '2' in the winter and summer in the first season, it led to the production of fruits of a greater diameter. Likewise, there were no significant differences in the fruit content of acidity or vitamin C and peel thickness in the first season, while in the second season the fruits of the control contained the highest acidity, and biochar '2' in the winter and summer gave the highest vitamin C. Total soluble solids of fruit increased with the control in the two seasons. This result agrees with those obtained by Madejon, *et al.,* (2003) who found that application of the organic amendments did not adversely affect quality.

Table 2: Effect of compost and biochar on vegetative growth characteristics and chlorophyll content of Valencia orange during 2017/2018 seasons.

Parameters	Leaf area (cm^2)		No. of shoots / one meter branch		No. of leaves/ Shoot		Shoot length (cm)		Total chlorophyll (CCI)	
Seasons / Treatments	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Compost 1	22.370 BC	24.890 B	14.000 BC	17.000 AB	24.300 B	27.000 AB	40.000 B	73.333 A	103.49 A	98.07 AB
Compost 2	21.170 C	21.550 C	15.660 B	18.000 A	22.000 C	29.333 AB	36.900 C	78.333 A	86.57 A	97.17 AB
Biochar 1	25.557 AB	27.673 A	13.840 BC	20.000 A	29.800 A	32.000 A	42.200 A	73.333 A	93.36 A	103.85 A
Biochar 2	24.150 ABC	27.793 A	18.160 A	17.667 A	22.500 C	31.000 AB	40.000 B	75.000 A	85.40 A	89.57 BC
Control	27.623 A	24.703 B	12.170 C	13.333 B	21.150 C	23.333 B	37.993 C	41.667 B	78.40 A	81.87 C

Values followed by the same letter/s over each column didn't significantly differ at 5% level

Table 3: Effect of compost and biochar on Valencia orange leaf minerals content during 2017/2018 seasons.

Parameters	N (g/100g)		P (g/100g)		K (g/100g)		Ca (g/100g)		Mg (g/100g)	
Seasons / Treatments	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Compost 1	3.02 A	3.07 A	0.400 B	0.500 A	1.95 A	1.41 B	5.50 B	5.50 A	0.390 AB	0.380 B
Compost 2	2.93 B	2.96 B	0.400 B	0.450 AB	1.38 C	1.84 A	4.80 B	5.20 AB	0.460 A	0.410 AB
Biochar 1	2.93 B	2.89 B	0.600 A	0.580 A	1.32 C	1.41 B	7.25 A	4.95 B	0.450 A	0.490 A
Biochar 2	2.98 AB	2.93 B	0.450 B	0.500 A	1.63 B	1.87 A	5.30 B	4.88 B	0.340 B	0.420 AB
Control	2.08 C	2.047 C	0.300 C	0.320 B	1.76 B	1.95 A	6.00 AB	5.15 AB	0.450 A	0.480 A

Values followed by the same letter/s over each column didn't significantly differ at 5% level

Adequate ranges for citrus leaf were: 2.4 - 3.5 (N), 0.15 - 0.3 (P), 1.2 - 2.0 (K), 3 – 7 (Ca), 0.25 - 0.7 (Mg). (Werner, 1992)

Table 4 : Effect of compost and biochar on Valencia orange leaf minerals content during 2017/2018 seasons.

Parameters	Fe (ppm)		Mn (ppm)		Zn (ppm)		Cu (ppm)		Na (g/100g)	
Seasons / Treatments	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Compost 1	140.0 AB	128.0 A	37.20 AB	35.90 A	11.00 B	12.00 A	5.00 B	5.00 C	0.130 C	0.200 A
Compost 2	96.00 C	74.00 C	28.20 BC	26.90 B	10.00 B	10.00 B	9.00 A	9.00 AB	0.320 A	0.140 B
Biochar 1	117.0 BC	91.00 BC	38.40 A	37.10 A	15.00 A	12.00 A	5.00 B	7.00 BC	0.270 AB	0.170 AB
Biochar 2	155.0 A	82.00 C	26.40 C	25.10 B	11.00 B	12.00 A	5.00 B	6.00 C	0.140 BC	0.180 AB
Control	120.0 BC	114.0 AB	27.80 BC	26.50 B	11.00 B	12.00 A	8.00 A	11.00 A	0.380 A	0.210 A

Values followed by the same letter/s over each column didn't significantly differ at 5% level

Adequate ranges for citrus leaf were: 35-135 (Fe), 19-50 (Zn), 19-100 (Mn), 5-15 (Cu)(Wutscher and Smith 1994)

Table 5: Effect of compost and biochar on yield and its components of Valencia orange trees during 2017/2018 seasons

Parameters	No. of fruit/tree		Fruit weight (gm.)		Yield/tree (kg.)		Tree canopy (m^3)		Crop efficiency (Kg/m^3)	
Seasons / Treatments	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Compost 1	216.67 A	231.00 A	196.67 A	273.61 ABC	42.425 A	63.181 A	69.840 A	88.372 AB	0.6103 AB	0.7283 B
Compost 2	208.33 A	198.00 AB	203.05 A	298.33 A	42.166 A	59.381 A	60.607 AB	71.599 ABC	0.6947 A	0.8343 AB
Biochar 1	123.33 B	187.00 BC	221.11 A	287.50 AB	27.080 B	53.571 AB	48.540 B	57.417 BC	0.5760 AB	0.9790 A
Biochar 2	148.33 AB	156.00 CD	211.39 A	258.89 BC	31.123 AB	40.621 BC	58.070 AB	95.757 A	0.4703 B	0.4263 C
Control	130.00 B	135.00 D	166.94 B	242.77 C	21.265 B	32.735 C	45.183 B	46.141 C	0.4697 B	0.7127 B

Values followed by the same letter/s over each column didn̍t significantly differ at 5% level

Table 6 : Effect of compost and biochar on fruit characteristics of Valencia orangeduring 2017/2018 seasons.

Parameters	Fruit diameter (cm.)		Peel thickness (cm.)		Total soluble solids (%)		Titratable acidity (%)		Ascorbic acid (mg/100 ml juice)	
Seasons / Treatments	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Compost 1	7.0633 AB	7.9663 AB	0.5053 A	0.5560 A	11.320 AB	11.933 B	2.1633 A	2.3667 BC	38.907 A	38.800 BC
Compost 2	7.1833 AB	8.2217 A	0.5220 A	0.5990 A	11.420 AB	11.933 B	2.0500 A	2.4667 B	44.960 A	37.800 BC
Biochar 1	7.7167 A	8.0997 A	0.5553 A	0.5990 A	10.907 B	11.433 B	1.9500 A	2.0333 C	40.480 A	33.400 C
Biochar 2	7.2400 AB	7.8630 AB	0.4780 A	0.4660 B	11.363 AB	11.933 B	2.2267 A	2.6333 AB	43.707 A	48.600 A
Control	6.6600 B	7.5663 B	0.5333 A	0.5990 A	11.873 A	13.300 A	2.0767 A	2.9000 A	48.400 A	43.800 AB

Values followed by the same letter/s over each column didn̍t significantly differ at 5% level

Conclusion

Some citrus trees in Egypt which are grown on reclaimed or sandy lands of low native fertility and low nutrient and water holding capacities have high probability that fertilizer "N" will leach beyond the root zone. The application of organic materials "compost" orbiochar as fertilizers or soil conditioners to those soils as a source of organic matter are recognized ways of improving their physical (water holding capacity), chemical (reduce fertilizer application) as well as biological properties. We can recommend adding biochar '1' once to trees as they gave the best vegetative growth represented by the shoot length and the number of leaves formed and their content of chlorophyll. It also gave the highest leaf content of phosphorous, magnesium, manganese and zinc, as well as the addition of compost '1' once was in the second rank. Such, the yield and its components were superior with the addition of compost '1- 2' once or twice, followed by biochar '1' once. Also, most of the fruit characteristics were not affected by these additions, especially in the first season.

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