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Use of Palm (*Poenix dactilyfera* L.) Fiber and Sewage Sludge Co Compost as Substrates in Soilless Crop System

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Abstract: The Co-Compostage (CC) of Palm (*Poenix dactylifera* L.) Fiber (PF) and Sewage Sludge (SS) at volume rate (1PF/1SS), mixed with Top Soil (TS) have been used as a substrate for cucumber cultivated in soilless crop system. Five substrates with volume ratio T (CC-TS) were tested: T (10-0), T (9-1), T (8-2), T (7-3) and T (6-4). They were compared to peat in nursery and to TS in *Cucumis sativus* L. crop production. Total porosity, bulk density, moisture content, rate of drainage, pH and electrical conductivity of T (8-2) and T (7-3) were relatively favorable for plant growth. After 45 days of growth and in comparison to peat, T (9-1), T (8-2) and T (7-3) gave the best parameters of root development: volume, architecture, length, number, best seedling growth and a positive correlation (R = 0.751) between root and shoot dry matter. After 120 days, cucumber attained the best root development under T (8-2) and T (7-3). Fruits production of these substrates was 40% higher than those of the control.

Key words: Palm fiber, sewage sludge, substrate, soilless crop, *Cucumis sativus* L.

INTRODUCTION

In soilless crops, the major problem encountered was the nutritional imbalance caused by an incompatibility with the combination: nutrient solution/substrate/species cultivation (Kasmi *et al*., 2012; Choi *et al*., 2011; Latigui *et al*., 2011). This imbalance may cause salinity in the substrate inducing, therefore, phytotoxicity (Munns, 2002) or mineral deficiencies harmful to plant growth (Kefford *et al*., 2007).

The physical properties such as the ability to retain water, the drainage rate and the rate of air through the pores (Ferreras *et al*., 2000) significantly influence the pH and Electrical Conductivity (EC) of the substrate (Choi *et al*., 2011). Outside the recommended range of 5.5 to 6.5 for pH (Babiker *et al*., 2004; De Paz and Ramos, 2004) and 1.5 to 2.5 msec cm^{-1} for EC (Skiredj, 2005) the physiological process of the plant may be impaired causing poor nutrient uptake. (Choi *et al*., 2010; Gomez *et al*., 2001).

In this study, date Palm (*Poenix dactylifera* L.) Kibers (PF) were used. Because, In the Maghreb countries, *P. dactylifera* is widely available and represents an original form of human development in very harsh climatic conditions (Baaziz, 2000; Genin *et al*., 2004). The PF has been associated with the Sewage Sludge (SS) as a horticultural substrate for cucumber (*Cucumis sativus* L.) cultivated in a soilless crop system. Many studies have demonstrated the positive effect of the land application of sewage sludge compost (Tiffany *et al*., 2000; Shober *et al*., 2003; Zebarth *et al*., 2000). It has high levels of organic matter and nutrients, particularly phosphorus and nitrogen (Amir *et al*., 2005; Jouraiphy *et al*., 2005). On the other hand, examples of successful value-added organic waste recycling have been reported recently in literature where compost made from organic wastes have been used as a peat substitute in nursery cultivation (Bugbee, 2002; Papafotiou *et al*., 2004; Benito *et al*., 2005; Grigatti *et al*., 2007; Caballero *et al*., 2009). Characteristics of fiber are desirable since it can improve the soil structure and is also cost effective and environmentally friendly (Ahmad *et al*., 2010; Sreekala and Thomas, 2003).

The physico-chemical modifications occurring during the Co-composting of sewage sludge (Scaglia *et al*., 2000; Liang *et al*., 2003; Saviozzi *et al*., 2004) and palm fiber were investigated. To overcome the risks incurred by the direct use of this waste in agriculture, co-composting is considered to be the best pretreatment to destroy the pathogens (Ouatmane *et al*., 2000; Amir *et al*., 2005), to transform organic components into stable humic

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components (Tuomela *et al*., 2000; Amir *et al*., 2004) and to reduce the bio-availability of trace metal elements (Lau *et al*., 2003).

In these experiments, the main physicochemical characteristics: porosity, bulk density, moisture content, percentage of drainage, pH and EC (Fan and Yang, 2007; Medina *et al*., 2012) of the five substrates tested were studied in the laboratory. In the greenhouse nursery, the effect of these different substrates were compared to peat in regards to seedling on growth and root development of cucumber since, according to (Ford and Lorenzo, 2001; Wolters and Jurgens, 2009) root development of a species depends on the characteristics of the substrates. Finally, in the experimental greenhouse, the root development and fruit production of the different substrates were assessed.

MATERIALS AND METHODS

Substrate components

Sewage sludge: The Sewage Sludge (SS) used comes from the treatment plant in the city of Tiaret (1°18'47"E/35°22'33"N) Algeria. Its pH, EC and C/N were 7.20, 3.34 m sec cm^{-1} and 35.38, respectively. The compound's (%) total Ca, active Ca, organic matter, C and N were 32, 15, 7.91, 4.6 and 0.13, respectively. In regards to other elements, its composition (ppt) of P, K, Cu, Zn, Mn and Fe were 90, 0.19, 143.2, 850, 177.12 and 94.33, respectively. The concentrations of trace metals in SS are below the hazardous threshold for human beings and the environment according to French standards: NF U44-041-1985 (Dudkowski, 2009).

Topsoil: Top Soil (TS) has a clay loam texture. Its organic C, total N, available P and exchangeable K were, respectively, 9.30, 25.92, 13.40, 29.30 mg kg^{-1}. Its pH, EC and CEC were 7.93, 1.16 m sec cm^{-1} and 15.80 meq/100 g of soil, respectively.

Palm fiber: The lignocellulosic fibers of *P. dactylifera* (PF) were taken from axil of palm leaf on the trunks of trees located at Ouargla (5°19'40"E/31°57'27"N) a city in southern Algeria. Fiber is preferable in terms of its availability cost, and ability to absorb water (Rozman *et al*., 2000). Biocomposites derived from natural fiber are likely to be more eco-friendly and can be referred to as green composites (John and Thomas, 2008).

Co-Compostage: The Co-Composting of SS and PF (CC) lasted 6 months in order to obtain mature compost (Semple *et al*., 2001). The proportion of the initial mixture had a corresponding (V:V). This mixture was allowed to obtain an essential volume for aerobic fermentation (Antizar-Ladislao *et al*., 2006) allowing the mineralization of organic matter by microorganisms (Laos *et al*., 2002; Grigatti *et al*., 2004). The compost was mixed with TP in different proportions to form five substrates used as the soil in the nursery and greenhouse experiments.

Plant material and growth conditions: The experiment was carried out in a greenhouse located in Tiaret (35-15N, 001-26E) Algeria. This greenhouse is equipped with irrigation drip system allowing for homogeneity of fertigation to the plants.

"Gueroum" C. Sativus was seeded on 02.27.2012 directly in cells of seed trays containing different tested substrates. The plants were irrigated with tap water during the first 45 days two times per day. After transplanting into 1.6 L pots filled with different substrates, hydro mineral solution was provided for plants until the harvest. The solution was composed of macro elements (meq L^{-1}): $8NO_3$-, $2H_2PO_4$-, $2SO_4$-, $5Ca^{+2}$, $5K^+$, $2Mg^{2+}$ and micro elements (μg L^{-1}): $1.81MnCl_2.4H_2O$, $2.86H_3BO_3$, $0.22ZnSO_4.7H_2O$, $0.08CuSO_4.5H_2O$, $0.09H_2MoO_4.H_2O$ and $0.79Na_2FeEDTA$ with pH = 5.5, EC = 2.5 m sec cm^{-1} and ratio (K^+)-$(Ca^{2+}Mg^{2+})$ = 0.71. According to Latigui (1992) this rate near 0.67 allows for the best uptake of all elements.

Steering of fertigation: Fertigation was applied with a localized drip-irrigation system. The EC and pH were adjusted at 2.5 m sec cm^{-1} and 5.5-6.5, respectively. The fertigation depended on the developmental stage of the plant as well as climatic factors (Salas and Urrestarazu, 2001). They were monitored every 3 days in the leaching solution with a pH-meter and EC-meter directly in the greenhouse. The EC of leaching even though increased over the time never reached values harmful to the growth of the plants.

The drainage rate was maintained at 30 to 40% of the input solution. This rate avoids salt accumulation in the root media (Latigui and Dellal, 2009; Munoz *et al*., 2008). Depending on these factors, fertigation was initiated between 3 and 4 min every 2 h during the day until sunset. Because, the irrigation in small quantities with high frequency is required to maximize the crop productivity in soilless crop (Schroder and Lieth, 2002).

Experimental design and measurements: Five substrates compounded by different T (CC-TS) volume ratios were tested: T (10-0), T (9-1), T (8-2), T (7-3) and T (6-4). They were compared to peat in nursery growth seedlings and to TS in cucumber crop production in greenhouse under soilless crop system with drip fertigation.

Experiment 1: Physical and chemical characteristics of substrates tested: In the first experiment the substrate's physical properties were determined by the methods of Spomer (1990) and Webber *et al.* (1999) for Total Porosity (TP), Bulk Density (BD), Moisture Content (MC) and Drainage Rate (DR).

The pH and EC were evaluated by employing the use of HI 9813 portable EC meter (Hanna Instruments, Woonsocket, RI, USA) and an AB 15 pH meter (Thermo Fisher Scientific, Waltham, MA, USA).

Experiment 2: Use of different substrates on seedling growth in nursery: The second experiment was conducted in a greenhouse nursery. It concerned the breeding of cucumber in cell filled by the five substrates studied. Forty-five days after sowing, plants were removed from their containers. The main parameters of root development cited by Wang *et al.* (2009) were studied. They included Root Volume (RV), Root Architecture (RA), Root Length (RL), Root Number (RN), Root Dry Matter (RDM) and Shoot Dry Matter (SDM).

The roots were carefully removed from the substrate and washed with water. Afterward, they were soaked in a graduated test tube filled with water to then measure the displaced water volume. This operation allows us to know RV. The upper part of volume from the collar to middle and the lower part from the middle to root apex allowed us to know RA. Because, it is represented by lateral roots clustering in the upper and lower region primary root (Fan and Yang, 2007). In this experiment the occupation percentage of the upper part of root to total volume was calculated.

RL was calculated from the collar to the apex of the main root. Because according to (Canadell *et al.* 1996) the vertical root distribution and maximum rooting depth both vary substantially between species and in relation to soil texture and nutrient availability. In addition a RN greater than 1 cm was counted.

Root samples and shoot fresh samples were oven-dried separately at 80°C for 48 h and weighed to determine the dry matter weight of each part. RDM-SDM ratios were then calculated.

Experiment: 3 Use of different substrates in the *C. cucumber* production in soilless crop system: The third experiment was conducted in experimental greenhouse. Seedlings of cucumber from each substrate were transplanted to pots of 1.5 L volume containing five substrates studied and the TS as control. After 120 days of growth, the length, volume and dry matter of roots as well as fruit production were studied.

Statistical analysis: A randomized design of experiment with five replications per treatment was conducted. Analysis of Variance (ANOVA) was used to analyze differences among the treatments for the chemical and physical characteristics, characteristics of root development and total fruit weight, using Statistica 7.5 beta software assistat. Comparisons of means were based on the Duncan test at 5 and 1% probability level.

RESULTS AND DISCUSSION

Experiment 1: Effect on physicochemical properties: For all results (Table 1), analysis of variance showed a highly significant effect on substrates physical properties, EC ($p<0.01$), pH ($p<0.5$) and on seedling growth (Fig. 1).

The presence of the high quantity of palm fiber in substrates of T (10-0), T (9-1) and T (8-2) significantly influenced the high TP (Table 1). According to

Fig. 1: Seedlings growth of cucumber in different substrates 45 days after sowing, T(10-0) T(9-1) T(8-2) T(7-3) T(6-4) Peat

Table 1: Average of main physico-chemical properties of different substrates tested

Treat	TP (%)	BD (gr cm^{-3})	MC (%)	DR (%)	pH	EC
T(10-0)	61^{a}	0.63^{b}	28^{bc}	40^{a}	5.75^{d}	2.34^{cd}
T(9-1)	60^{a}	0.59^{b}	37^{a}	40^{a}	6.96^{c}	2.86^{bc}
T(8-2)	60^{a}	0.59^{b}	31^{ab}	37^{ab}	7.54^{a}	2.18^{d}
T(7-3)	48^{b}	0.67^{b}	30^{bc}	31^{b}	7.45^{ab}	3.01^{b}
T(6-4)	43^{b}	0.99^{a}	23^{c}	24^{c}	7.19^{bc}	4.22^{a}
Tests	**	**	**	**	*	**

[z]Mean separation by Ducan's multiple range test at $p<0.01$. Values followed by same letter within columns are not significantly different.*** significant at $p<0.05$ and 0.01, respectively.

Bilderback *et al.* (2005), Chong (2005), and Vaughn *et al.* (2011) TP in the substrates must be in the range 50-85%. It can change as the substrate degrades over time and as root mass increases and becomes a better indicator for root distribution (Dexter, 2004; Asgarzadeh *et al.*, 2010).

The substrate T (10-0) gave a higher BD 0.99 g cm^{-3}. While desirable values are 0.15 for vermiculite, 0.14 for peat moss and 0.75 g cm^{-3} for composts (Vaughn *et al.*, 2011; Noguera *et al.*, 2003; Monedero *et al.*, 2004) obtained by T (10-0), T (9-1), T (8-2) and T (7-3); substrates composed of CC. These results were also found by Chimonidou-Pavlidou (1999) on perlite.

The results (Table 1) showed that substrates composed by CC gave the highest of MS with 37% for T (9-1). With regard to different substrates, Chimonidou *et al.* (2007) showed that MT varies between 25-65%. These results coincide with those of the substrates compounded by CC in our experiment.

The results (Table 1) showed that DR increases with a rise of CC in the substrates. T (10-0), T (9-1), T (8-2) and T (7-3) gave a DR with a range of 31-40 (Roeber ,1999; Choi and Latigui, 2008) have shown that such rates avoid water-logging, which is harmful for plant growth (Morard *et al.*, 2000; Adams, 2002).

The pH of leaching must vary between 5.5 to 6.5 (Urrestarazu *et al.*, 2008; Abad *et al.* 2001). The results (Table 1) showed that the pH of all treatments is relatively higher. This is due to the lack of NO_3 (Choi *et al.*, 2011) and to the form of nitrogen present in the substrates (Domeno *et al.*, 2009; Hussein, 2009). The contribution in the nutrient solution of an acidifying such fertilizer as NH_4NO_3 allows for the improvement of the pH (Babiker *et al.*, 2004). Hence, in this experiment pH has been previously adjusted to 5.8-6.0 in input nutrient solution for further experimentation.

A significant rise of drainage EC compared to those of input solution causes harmful salinity causing phytotoxicity (Latigui, 1992; Choi *et al.*, 2011) and impairs the product quality and quantity (Tabatabei *et al.*, 2006). The results (Table 2) showed that the largest proportion of the CC present in T (10-0), T (9-1) and T (8-2) gave an ideal EC 2.18-2.34 m sec cm^{-1}. This range improves fruit quality and antioxidant content (De Pascale *et al.*, 2001; Keutgen and Pawelzik, 2007; Choi and Latigui, 2008; Skiredj 2005; Acuna, 2007) and decreases the risk of salinity compared to T (6-4). Hence T (10-0), T (9-1) and T (8-2) allows us to increase the concentration of nutrients in input solution without the risk of increasing the substrate salinity.

Experiment 2: Use of different substrates on seedling growth in nursery

Root development: Except for RN, all root growth parameters of *C. cucumis*, 45 days after sowing were significantly influenced by various CC ratios in the substrates (Table 2). Nevertheless, the unique contributions of CC in T (10-0) resulted in a decrease of the plant growth. The peat substrate gave chlorotic plants (Fig. 1).

The incorporation of 70 and 80% of CC in the substrates T (8-2) and T (7-3) (Table 2) gave the highest RV. The lowest value was obtained by the Control compound by a peat. Cox (2001) and Nemali and van Iersel (2004) showed that both wetness and salt stratification reduces root colonization. On the other hand, macro and micro-nutrient contents are important constituents in potting mix (Alburquerque *et al.*, 2004; Raviv *et al.*, 2007). Hence the characteristic of T (8-2) and T (7-3) presents itself as a potential ingredient for the production of growth media in nursery cultivation.

The results showed that the Root Distribution (RD) in substrate is relatively homogeneous in T (8-2), T (7-3) and T (6-4) between the upper and lower part of substrates compared to other treatments (Table 2). In peat substrate 90% of the root is located in the upper part. According to (Santamaria *et al.*, 2003; Nemali and van Iersel, 2004; Zheng *et al.*, 2004; Matysiak and Bielenin, 2005; Rouphael *et al.*, 2008), the root occupation in the upper part of substrate is due to the drip irrigation system. While, the occupation of the lower part is due to the sub irrigation system (Cox, 2001; Nemali and van Iersel, 2004). Likewise, Rouphael and Colla (2005), Fitter *et al.* (2002) and Bouma *et al.* (2001) estimated that salt accumulation at the substrate surface is a major drawback of this cultural drip irrigation technique. Whereas, in this experiment, the introduction of CC in the substrates determined significantly the spatial distribution independent of the nutrition and the irrigation system. Because, it used the same fertigation with the drip system for all treatments.

RN has often been used to characterize root development in soil (Vercambre *et al.*, 2003; Dvoralai and Jens, 1999). In this experiment, the number of roots was not influenced by the substrates used. By comparison, the average maximum RL varied significantly ($p<0.01$) among the substrates (Table 2). The longer roots were

Table 2: Influence of different substrates on main parameters of root development of seedling cucumber 45 days after sowing

Treat	RV (cm^3)	RD in Upper part (%)	RN	RL (cm)	RDM (g)	SDM(g)	RDM-SDM ratios
T(10-0)	5^c	80^{bc}	17^a	20^{ab}	0.14^b	0.71^c	0.19^a
T(9-1)	6^b	83^{ab}	19^a	19^{ab}	0.17^{ab}	0.95^{bc}	0.17^{ab}
T(8-2)	8^a	75^c	19^a	19^{ab}	0.23^a	1.25^{ab}	0.18^a
T(7-3)	8^a	75^c	20^a	25^a	0.23^a	1.5^a	0.15^{bc}
T(6-4)	5^c	60^c	21^a	19^{ab}	0.21^a	1.28^{ab}	0.16^{bc}
Peat	2^d	90^a	18^a	17^b	0.12^b	1.17^{ab}	0.10^c
Tests	**	**	NS	*	**	**	**

[z]Mean separation by Ducan's multiple range test at $p<0.01$. Values followed by same letter within columns are not significantly different. NS,*,**nonsignificant or significant at $p<0.05$ and 0.01, respectively

obtained in T (7-3) and the shorter in the peat. Hence, apparent discrepancies between averages root length distributions results from variation within substrates. Likewise, according to (Krasilnikoff *et al*., 2003), root length may play an active role in ions and water uptake and it is used to characterize root development in soil (Pierret *et al*., 2000). Consequently, the substrate T (7-3) exhibited these characteristics relative to the other treatments.

The greatest RDM was obtained in T (8-2), T (7-3) and T (6-4) (Table 2). Andrews *et al*. (2001) showed that moderate drought stress could lead to an increase of dry root matter. In our case, the substrates used received a dose of fertigation according to a drainage rate equal to 30-40% of input dose for all treatments. Thus, the only factor that differentiated the treatment was the rate of CC in the substrates.

SDM (Table 2) also showed significant differences between substrates. For instance, T (7-3) is higher than the other treatments. This means the introduction of CC in substrates played a main role. Similarly, Rubio *et al*. (2009) and Grigatti *et al*. (2007) showed that nutrients condition affects shoots.

The average value RDM-SDM ratio in T(10-0) was significantly ($p<0.01$) higher than the other treatments. The high positive correlation ($r = 0.751$) was showed between the dry matter of the both parts (Fig. 2). It seems decrease that there was a from high rate of CC in substrate to low rate. Casadesus *et al*. (2007) reported that an increase of this ratio was noted under a lack of water conditions. This corresponded to T(10-0) in this experiment. The choice of a growing medium with an optimal balance between water availability and root aeration is crucial for optimizing yield and quality in horticultural crops.

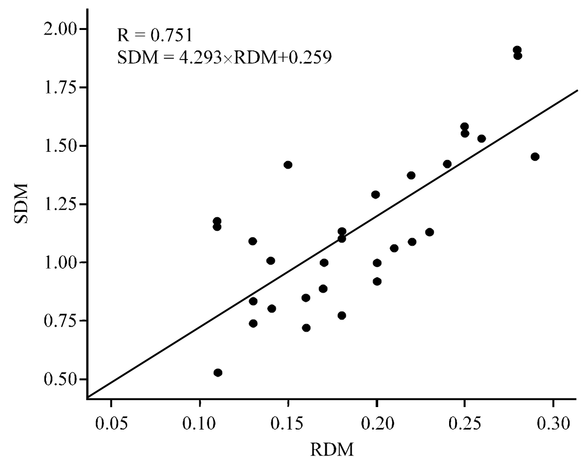

Fig. 2: Correlation between root and shoot dry matter 45 days after sowing ($p<0.01$)

Table 3: Influence of different substrates on root development and fruit production of *cucumber* 120 days after sowing

Treat	RV (cm^3)	RL (cm)	RDM (g)	Fruits production(kg)
T(10-0)	12.5^b	18.5c	0.75^c	6^{ab}
T(9-1)	12.5^b	28.5^b	0.95^{bc}	6.3^{ab}
T(8-2)	20^a	32.5^a	1.45^b	7.3^a
T(7-3)	20^a	33.5^a	2.55^a	7.3^a
T(6-4)	10^c	20.25^c	1.05^{bc}	5.2^{bc}
TM	12^{bc}	17.5^c	1.35^b	4.4^c
Tests	*	**	**	**

[z]Mean separation by Ducan's multiple range test at $p<0.01$. Values followed by same letter within columns are not significantly different.*,**significant at $p<0.05$ and 0.01, respectively

Experiment 3: Use of different substrates in the *C. cucumber* production in soilless crop system: At the end of the growing season and after harvesting the fruit, the results (Table 3) showed that the effect of different substrates on root development is very significant. For all the studied parameters T (8-2) and T (7-3) gave, relatively, the best conditions for optimum root development. Most of their parameters are within the acceptable and optimal ranges specified for growth media in potted plant production as reported by Abad *et al*. (2001). Therefore, the greatest weight in fruits was obtained with both substrates. It was 40% higher than those of the control. Dexter (2004) and Wang *et al*. (2006) also, showed that the soil texture and structure have major effects on root growth and on their distribution.

Benjamin and Nielsen (2006), Songsri *et al*. (2008) and (Engel and Kirkby, 2001) showed that under unfavorable conditions of soil water content, plants enhance their ability for improving water uptake through extending the rooting system and increasing root length density. By comparison, in our experiment these two parameters were exclusively the consequence of the introduction of 70 and 80% of CC. Recent research on peat replacements for greenhouse tomatoes has centered on the use of various composts(Garcia-Gomez *et al*., 2002; Farrell and Jones, 2010).

CONCLUSION

Palm (*P. dactylifera* L.) fiber and sewage sludge co compostage at volume rate (v/v) mixed with topsoil have been used as peat substitutes in nursery cultivation and as substrates for cucumber (*C. sativus* L.) cultivated in soilless crop system.

The main physical-chemical properties: total porosity, bulk density, moisture content, rate of drainage, pH and Electritical Conductivity (EC) of substrates compounded by 70 to 80% of Co-compostage gave 100% of germination and the best seedling growth in nurseries after 45 days compared to a peat substrate. After 120 days of growth under a soilless crop system, cucumber crops in these substrates, also gave the best parameters of root development. The fruit production was 40% higher under these substrates than those under top soil.

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