Comparative effects of inorganic and organic compost fertilization on lettuce (*Lactuca sativa* L.)

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Abstract: - The aim of this study was to evaluate the agricultural use of a commercial compost as a soil organic amendment, its effect on weed occurrence and its residual fertilizer effect on soil. The tested crop was greenhouse lettuce (*Lactuca sativa* L.). The plants were grown in randomized pots under three types of fertilization, as follows: no fertilization (control); an inorganic fertilizer (NK) and an organic commercial compost (Organical®, Terra Fertil, Portugal), prepared with urban sewage sludge, crop, garden and forest residues. The results showed a higher growth of lettuce fertilized with the compost than with the inorganic fertilizer. Lettuce growth enhanced monotonically with the increase of the compost concentration until 6.0 kg of compost m^{-2}, but at this rate, yield (fresh weight of canopy) did not differ statistically from the dose of 3.0 kg of compost m^{-2}. No increase of plant leaves micronutrient content was observed, except on the 6.0 kg compost m^{-2} treatment, where a low increase of zinc was determined. Weed number increased under lower doses of the compost, indicating that compost was not contaminated with weed seeds and, nevertheless its maturity, compost exhibited some control of weed germination. The residual fertilizer effect of the compost on a second lettuce crop was not statistically observed. Hence, according to the experimental results, it was suggested the amount of 3.0 kg compost m^{-2} (30 t ha^{-1}) as the best application rate, due to the higher growth and lettuce yield, and the lower occurrence of weeds. On the other hand, as the possible destinations of urban sludge and other biosolids (sea, deposition in land fields and incineration) provoke environmental problems, their agricultural reuse as ”compost” is essential to avoid those problems.

Key-Words: growth, environment, yield, weeds, nutrients, biosolids.

I. INTRODUCTION

Biosolids are a common soil amendment that improves soil fertility by incorporating a variety of plant nutrients such as nitrogen, phosphate and potassium, as well as a large proportion of organic matter [1]. Residues, such as urban sewage sludge, industrial biosolids and crop, garden and forest residues, can be transformed into compost and used as horticultural substrate component [2] or as an alternative to the use of the inorganic fertilizers. The use of sewage sludge compost is already known as a horticultural substrate component, and chemical analysis showed that there was no potential hazard for its use [3]. On the other hand, urban sewage sludge showed a nitrogen use efficiency of 45 % and there was practically no nitrogen loss by leaching, once that organic mineralisation of the sludge compost slowly released the nitrogen to the crop, avoiding nutrient losses to the soil profile [4]. The Mediterranean environment is characterized by important annual losses of organic material. Given the environmental impact of mineral fertilization, organic fertilization might be a better option, with benefits to the plant, the soil and the environment [29]. As fertilization and irrigation practices appears to be some of the nitrate pollution sources, the use of the new organic residues must be investigated [5]; on the other hand, it was proved that the adequate management on the application of inorganic fertilizers reduce nitrogen leaching problems in soil and groundwater [6]. The application of compost to the soil is environmentally sustainable, particularly in lower fertilty soils, characteristic of southern Portugal, increasing soil fertility and improving crop production [8]. Other organic fertilizers have been successfully applied to horticultural crops, such as manure [7], sugar cane [8] and carob [9] residues. Compost was already applied to lettuce (*Lactuca sativa* L.) as organic fertilizer, and quantitative and qualitative yield aspects were studied [10]. However, specific responses of lettuce (*Lactuca sativa* L.) to the soil incorporation of composted sludge municipal wastes are higher when they are applied with fertilizer management programs [11]. The present study is focused on the response of lettuce yield (*Lactuca sativa* L.) to an organic commercial compost (Organical®, Terra Fertil, Portugal), prepared with: urban sewage sludge; and crop, garden and forest residues; the residual effect on a following crop, and the effect on weed occurrence.

II. MATERIAL AND METHODS

A. Experimental procedure

The experimental plot was established in a greenhouse, during the Spring an Summer of 2010, in the Campus of Gambelas of the University of Algarve, Faro, the southern region of Portugal, according to Figs. 1 and 2.

The crop selected for the study was a spring lettuce, *Lactuca sativa* L. ‘Vanity’, characterized by a long growing cycle (45-70 days).

The experiment was accomplished in 4 L pots, distributed randomly in three replications, with 3 pots per replication and treatment, according to the following 6 treatments (T0, T1, T2, T3, T4 and T5), as follows: T0 - control (no fertilization), T1 – NK, T2 - 0.6 kg compost m^{-2}, T3 - 1.5 kg compost m^{-2}, T4 - 3.0 kg compost m^{-2} and T5 - 6.0 kg compost m^{-2}.

The control (T0) was a natural sandy soil, and the other treatments were obtained after mixing it with chemical fertilizer (T1) or compost (T2 – T5). The commercial compost (Organical®) and an inorganic fertilizer were incorporated up to 0.10 m depth, manually. NK treatment (T1) was obtained with ammonium nitrate (with calcium) (1.12g pot^{-1}) and potassium chloride (0.85g pot^{-1}). There was no need to apply a phosphorous fertilization, according to the soil chemical analysis.

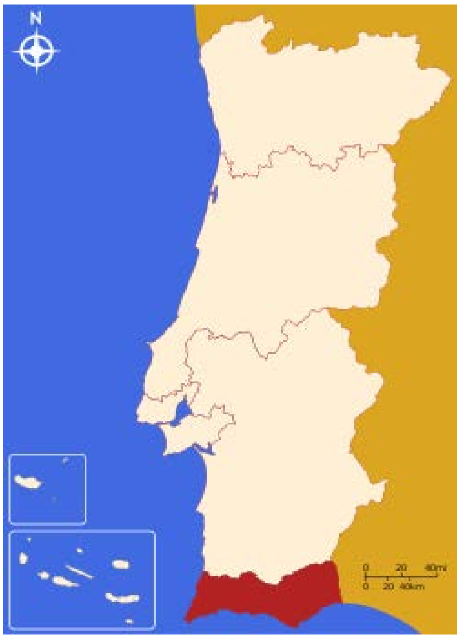

Fig. 1 - Map of Portugal. Algarve region is identified by a brown colour.

Fig. 2 - Experimental area.

Plant spacing was 0.35 m x 0.25 m, and the pots where placed in a greenhouse, with shade cloth and mechanical ventilation (Fig. 3).

Fig.3 - Plant spacing in a greenhouse.

A drip irrigation system was used – Netafim compensating drippers, with a constant 8 L h^{-1} discharge, being two dripper per pot (Fig. 4). Plants were daily irrigated, with a water amount according to FAO evaluation [13].

Fig. 4 – Drip irrigation system applied to the greenhouse lettuce experiments.

During the trial, the emerged weeds were counted every week, to determine if the compost was contaminated by weeds, or had any effect on weed occurrence. After this crop, plant roots were carefully removed and a second lettuce crop was installed, following the same experimental design, with the objective of evaluating the residual effect of the compost applied before the first crop.

B. Climate

The climate of the Algarve region can be considered as Mediterranean, in particular the south shore [12]. After Köppen [25], it is classified as Csa (Mediterranean climate), with semi-arid characteristics, identified by mild rainy winters and by warm and dry summers. In the greenhouse, air temperature during the experiment reached very high values. Hence, the average of maximal daily temperature was 31.9 º C, being the average of minimal daily temperature 15.4 º C (Fig. 5).

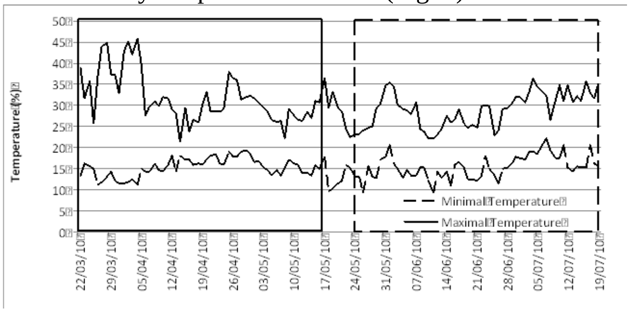

Fig. 5 – Average minimum and maximum daily temperature inside the greenhouse during the experiment - first lettuce crop (within rectangle with solid line); second lettuce crop (within rectangle with dashed line).

The daily air relative humidity highly varied along the day. During the night, its value reached almost 90 %, but during the day decreased to very low levels, reaching the minimum value of 9.4 % on the 4th April (Fig. 6).

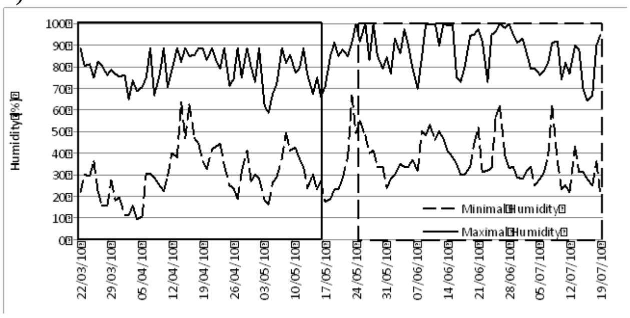

Fig. 6 – Average minimum and maximum daily relative humidity inside the greenhouse during the experiment- first lettuce crop (within rectangle with solid line); second lettuce crop (within rectangle with dashed line).

C. Plant growth measurements

Plant growth was evaluated along the experimental period [14]. At weekly interval the green colour intensity - chlorosis degree total chlorophyll - was recorded. The chlorosis degree was estimated through the use of a chlorophyll meter (SPAD-502, Minolta Co., Osaka, Japan), which determines the pigment content on the leaves [15], allowing the correlation between the determined and the experimental values [16], or other pigments extracted by conventional procedures. At the end of the trial, when plants reached the commercial size, it was measured plant height, the diameter of stems, the diameter of canopy, the number of leaves, canopy fresh weight, canopy dry weight, root fresh weight and root dry weight. It was computed the ratio between dry weight of the plant canopy and of the total plant (DWCT), ratio between dry weight of the root system and the total plant (DWRT) and ratio between dry weights of the plant root system and of the plant canopy (DWRC). This procedure was followed also in the second cultivation trial.

D. Laboratory analyses

Descriptions of soil and compost chemical analysis done before and at the end of the experiment are presented in Table 1. At the end of the experiment, the chemical analysis of the mixes (soil + compost or fertilizer) was done for all treatments and replications.

Table 1 – Analyses of soil and compost: chemical parameters before and at the end of the experiment.

Parameter		Analysis method
Organic matter		Walkley and Black [18]* Burnt at 560º [19]**
pH		Electrometry – water extract (1:2.5) [20]* Electrometry – water extract (1:2) [25]**
Electrical conductivity (EC)		Electrometry – water extract (1:5)* Water extract after filtration**
Total N		Kjeldhal
$N\text{-}NO_3^-$		$CaCl_2$/DTPA
$N\text{-}NH_4^+$		$CaCl_2$/DTPA
K_2O		Photometry
P_2O_5		Modified Olsen* Colorometry**
Trace elements	Cu	Lakanen and Ervio [21] Atomic Absorvation Spectrophotometry
	Zn	
	Hg	
	Cd	
	Ni	
	Pb	
	Cr	

*Soil method
**Compost method

Plant chemical analysis was also done for all the treatments. Table 2 shows the description of plant chemical parameters analysed after the experiment.

Table 2 – Analyses of plant chemical parameters after the experiment.

Parameter	Analysis method
NO_3^-	$CaCl_2$/DTPA*
NH_4^+	$CaCl_2$/DTPA
P	Colorometry
K	Flame Fotometry
Ca	
Mg	
Fe	Lakanen and Ervio [21]
Cu	Atomic Absorvation Spectrophotometry
Mn	
Zn	

*DTPA – Diethylenetriamine pentaacetic acid.

According to Table 3, chemical parameters were higher in compost than in the soil.

Table 3 - Soil and compost chemical parameters values[1] before the experiments.

Parameters	Soil[1]	Compost[1]
MO (%)	1.20***	20.00***
pH (H_2O)	6.32*	7.03*
EC (dS m^{-1})	0.20***	9.17***
Total N (%)	0.10***	1.21***
NH_4^+ (ppm)	8.20**	15.00**
NO_3^- (ppm)	8.20***	69.00***
P_2O_5 (ppm)	70.0***	552.0***
K_2O (ppm)	10.0***	165.0***

[1] On each line, average value present significant differences at: *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$.

Table 4 shows the concentration of trace elements in the compost, and maximal recommended values [22].

Table 4 – Trace elements of the compost before the experiment, and maximal recommended values, according to Classification I and II.

Trace elements	Compost	Maximal values (class. I)	Maximal values (class. II)
Cu (ppm)	65	100	200
Zn (ppm)	356	200	500
Cd (ppm)	0.55	50	100
Ni (ppm)	39.2	100	150
Pb (ppm)	25.8	0.7	1.5
Cr (ppm)	9.2	10	15
Hg (ppm)	0.4	0.7	1.5

In general, according to classification II of recommended trace elements, the compost may be used for agricultural purposes [22]. Trace elements content may limit their use to the agricultural soils when pH < 7, but for higher pH, Zn is the only limiting factor for its application. The compost presented advisable values for agricultural uses, according to the values of organic matter concentration, pH, nitrogen, phosphorous and potassium [23]. Electrical conductivity is relatively high, and may cause damage to sensitive crops (Table 3 and Table 4).

E. Statistical analysis

The statistical program SPSS 11.0 [24] was used for the analysis of the data. Multifactor and one-way (ANOVA) were used to analyze values and averages were compared by Duncan Multiple Range Test (DMRT).

III. Results

A. Plant development

Table 5 shows the average values of the studied growth parameters, from the six treatments. Plant height increased when the compost concentration increased in the soil, although not statistically significant. The diameter of the stem increased monotonically with the amount of compost. It was detected the lowest development in treatment T0 (control), except for the canopy diameter, where there was a decrease in treatments T2 and T3.

Table 5 – Plant development[1] on the first lettuce crop: growth parameters.

Treatment	Height (mm)	Stem diam. (mm)	Canopy diam. (mm)	nº of leaves $plant^{-1}$
T0	115a	12.6c	246bc	28.1b
T1	125a	13.4c	247bc	28.0b
T2	119a	13.7c	241c	28.4b
T3	125a	15.0b	241c	32.3a
T4	130a	17.5a	283ab	32.3a
T5	135a	16.9a	299a	33.0a

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test).

In the trial, the residual effect, of the compost applied to the first lettuce crop, on the second crop was positive for the plant height and leaf number, and the remaining variables also did not present any significant statistical differences between the treatments (Table 6).

Table 6 – Plant development[1] on the second lettuce crop: growth parameters.

Treatment	Height (mm)	Stem diam. (mm)	Canopy diam. (mm)	nº of leaves $plant^{-1}$
T0	82.0ab	10.1a	197.5a	34.7ab
T1	74.3b	10.7a	203.7a	35.6ab
T2	75.9b	10.4a	221.5a	33.2b
T3	77.5b	10.9a	222.5a	34.4ab
T4	85.0ab	10.5a	214.7a	35.4ab
T5	97.1a	9.7a	203.8a	37.3a

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test).

Fig.7 shows SPAD (Chlorophyll meter) values of the leaves, measured along the experiment. The results showed an increase with the increase of the compost applied. Initially, the measured values were not statistically different, despite the higher values observed in the treatment T1 (NK), which shows the rapid effect of the chemical fertilization and in low compost dose treatments (T2 and T3). During all the experiment, the treatment T0 (control) showed the lowest value of SPAD, readings may indicate chlorosis, mainly resulting from nitrogen deficiency [17].

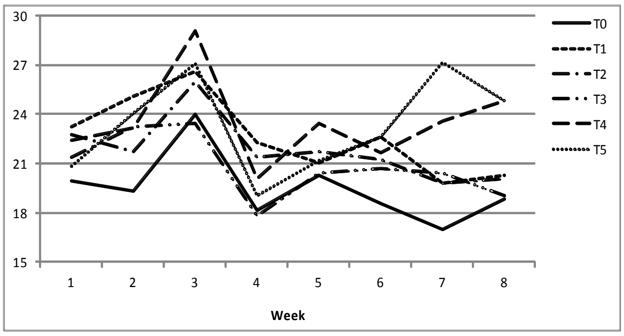

Fig. 7 – SPAD values along the first lettuce crop.

Initially, treatment T1 (NK) showed higher SPAD values, but these values progressively decreased. By the middle of the experiment, treatment T5 (higher compost application) presented intermediate SPAD values; but exhibited the highest SPAD values at the end of the experiment. This increase on SPAD value may explain the more permanent effect of the compost in the soil, specially the slower nutrient release, sustaining plant growth during a longer period than the inorganic fertilization (Fig. 7).

In the second lettuce crop, no significant differences between the SPAD values of the several treatments were determined. However, a positive evolution was observed related with the compost dose application. T5 showed a higher SPAD value initially, and both, T0 and T1, had higher values in the 2nd and 3rd weeks. There is a tendency for more favourable evolution of the SPAD values in the modalities with compost. At the end of the trial, the higher values registered were in the T3, T4 and T5 modalities, with T0 showing a tendency for decrease (Fig 10).

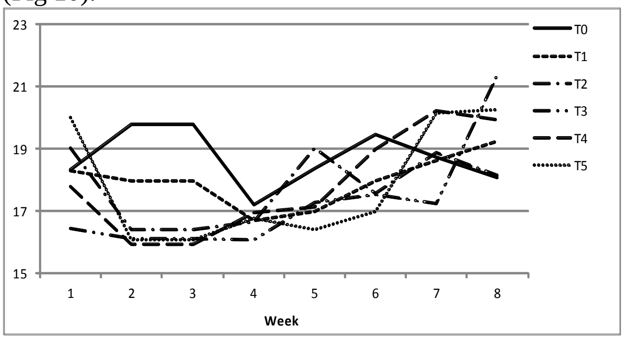

Fig. 8 - SPAD values along the second lettuce crop.

Figs. 9 and 10 show the plant development during and by the end of the experiments, respectively.

Fig. 9 - Plant development during the experiments

Fig. 10 - Plant development on the end of the experiments, second lettuce crop.

B. Crop yield

Fresh and dry weight of plant root and canopy per treatment (g $plant^{-1}$), are shown on Table 7. It may be seen the monotonic increase of plant yield with the increase of compost application. In trials using green pepper, the increase of sugarcane residues in the soil increased the organic matter and root development [8].

Table 7 - Fresh and dry weight[1] of plants on the first lettuce crop.

	FWC (g)	DWC (g)	RFW (g)	RDW (g)
T0	73.2e	6.27c	13.0c	1.85b
T1	108cd	5.39c	11.0c	1.41b
T2	86.3de	6.44c	14.1c	1.91b
T3	121bc	9.93b	18.9b	2.63b
T4	144ab	11.0ab	25.0a	4.84a
T5	154a	12.4a	24.1a	5.16a

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test). FWC - fresh weight of canopy; DWC - dry weight of canopy; RFW - root fresh weight; RDW - root dry weight.

In the second lettuce crop (Table 8), fresh and dry weight decreased in all treatments, regarding the first crop. Plant growth variables did no showed significant differences, although FWC and DWC did present a general tendency to increase with the increase of compost. These results may be partially explained by the low residual effect of the compost applied to the first crop, and by climatic conditions during this period. The minimal temperature inside the greenhouse was higher than 15ºC and the maximum temperature overcome 30ºC (Fig. 5), causing the formation of matured heads, that remain too small. This situation favours the starting of the reproductive phase, given the higher temperatures associated to long photoperiod [27].

Table 8 - Fresh and dry weight[1] of plants on the second lettuce crop.

	FWC (g)	DWC (g)	RFW (g)	RDW (g)
T0	30.2a	3.29a	12.0a	1.66a
T1	31.2a	3.60a	13.1a	2.19a
T2	33.1a	3.31a	10.9a	1.81a
T3	34.5a	3.61a	13.8a	2.02a
T4	35.1a	3.79a	12.1a	1.77a
T5	37.2a	3.58a	15.3a	2.64a

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test). FWC - fresh weight of canopy; DWC - dry weight of canopy; RFW - root fresh weight; RDW - root dry weight.

Plant weight ratios on the first lettuce crop are presented on Table 9. T4 and T5 showed the lower DWCT however, but the higher DWRT. Also DWRC had higher values in T4 and T5, showing a better root development in the modalities with compost.

Table 9 - Plant weight[1] ratios on the first lettuce crop.

	DWCT	DWRT	DWRC
T0	0.753ab	0.247ab	0.335ab
T1	0.819a	0.181b	0.224b
T2	0.775ab	0.225ab	0.295b
T3	0.784a	0.215b	0.281b
T4	0.703b	0.297a	0.455a
T5	0.704b	0.297a	0.440a

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test). DWCT - ratio between dry weight of the plant canopy and of the total plant; DWRT - ratio between dry weight of the root system and the total plant; DWRC - ratio between dry weights of the plant root system and of the plant canopy.

There were no significant differences between modalities in the second lettuce crop (Table 10), indicating no residual effect of the compost.

Table 10 - Plant weight[1] ratios on the second lettuce crop.

	DWCT	DWRT	DWRC
T0	0,698a	0,302a	0,567a
T1	0,685a	0,315a	0,629a
T2	0,690a	0,310a	0,548a
T3	0,680a	0,320a	0,587a
T4	0,714a	0,286a	0,456a
T5	0,670a	0,330a	0,652a

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test). DWCT - ratio between dry weight of the plant canopy and of the total plant; DWRT - ratio between dry weight of the root system and the total plant; DWRC - ratio between dry weights of the plant root system and of the plant canopy.

D. Weed number

During the first lettuce crop, it was observed that the incorporation of the compost in the soil did not increase the emergence of monocotiledonae weed species, (Fig. 11). No monocotiledonea were observed in the treatments T2, T3 and T5. On the other hand, it was seen an increase of monocotiledonae in the treatments T0, T1 and T4 in both lettuce crops. The higher number of monocotiledonae was observed in T0 and T4 (Fig. 11).

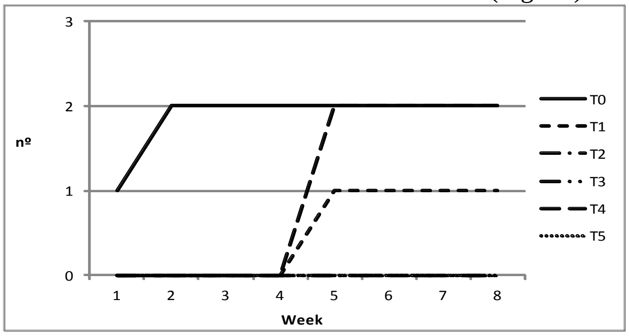

Fig.11 – Number of emerged monocotiledonae weeds per treatment, on the first lettuce crop.

During the second lettuce crop similar results were obtained (Fig. 12).

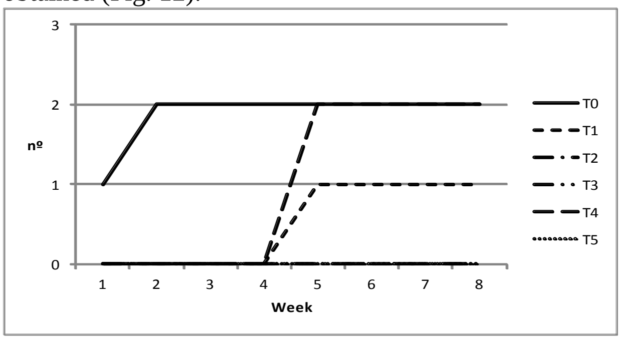

Fig.12 – Number of emerged monocotiledonae weeds per treatment, on the second lettuce crop.

Dycotiledonae weeds were not observed during the first lettuce crop in treatment T5 (higher compost amount). On the other treatments (T1 to T4), a low number of dycotiledonae weeds was recorded. On the other hand, treatment T0 showed the higher number of dycotiledonae weeds (Fig. 13).

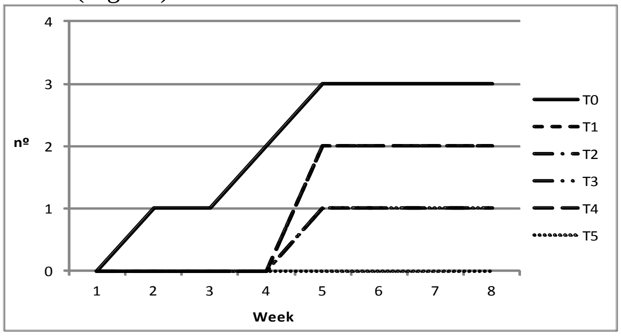

Fig. 13 – Number of emerged dicotiledonae weeds per treatment, along the first lettuce crop.

During the second lettuce crop similar results were obtained (Fig. 14).

It was previously reported that when compost was applied to soil, either on surface or incorporated, the number of weed species decreased [26], by avoiding light penetration, namely the penetration of certain wave lengths needed for plant development [28].

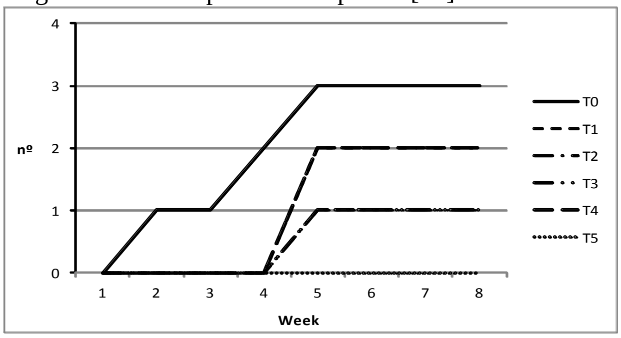

Fig. 14 – Number of emerged dicotiledonae weeds per treatment, along the second lettuce crop.

E. Plant chemical parameters

Tables 11 and 12 show, respectively, nitrogen content in lettuce leaves, for the different treatments at the end of the experiment, on the first and second crops.

The analysis of leaves show higher total, ammonium and nitric nitrogen content on treatment T1 (NK), where the chemical fertilizer was applied, followed by the compost treatments (Table 11).

Table 11 – Total N, NH_4^+ and NO_3^-content[1] in lettuce leaves, for the different treatments, at the end of the experiment, on the first lettuce crop.

	Total N (%)	NH_4^+ (ppm)	NO_3^- (ppm)
T0	1.41c	59.0c	13.8b
T1	2.24a	81.8a	45.5a
T2	1.63bc	60.1bc	14.8b
T3	1.36c	54.9c	18.6b
T4	1.43bc	71.0ab	16.8b
T5	1.76b	60.4bc	24.7b

[1] On each column, average with the same letter do not present significant differences at 95% (multi average comparison - Duncan test). Total N - total nitrogen; NH_4^+ - ammoniacal nitrogen; NO_3^- - nitric nitrogen.

In the second lettuce crop, T5 showed higher values of total nitrogen and amoniacal nitrogen. The composts display a slow release of nutrients, which might justify the higher nitrogen content in the leaves of the second crop in the treatment with more compost (greater nitrogen content) (Table 12).

Table 12 – Total N, NH_4^+ and NO_3^-content[1] in lettuce leaves, for the different treatments, at the end of the experiment, on the second lettuce crop.

	Total N (%)	NH_4^+ (ppm)	NO_3^- (ppm)
T0	1.85ab	139.1ab	33.1b
T1	1.74ab	139.2ab	17.8a
T2	1.81ab	86.0b	13.9a
T3	1.87ab	94.3b	18.5a
T4	1.64b	93.3b	21.8a
T5	1.92a	203.3a	60.6a

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test). Total N - total nitrogen; NH_4^+ - ammoniacal nitrogen; NO_3^- - nitric nitrogen.

Tables 13 and 14 show macronutrients content (P, K, Ca and Mg) in the leaves, for the different treatments at the end of the experiment, on the first and second crops. As expected, compost application increased the nutritive content of the leaves [9].

On the first lettuce crop, higher P and K concentrations were determined for treatment T5 (higher compost amounts), and the opposite for Mg content (Table 13). Treatment T1 showed a higher calcium concentration due to the composition of the chemical fertilizer.

Table 13 – P, K, Ca and Mg average content[1] in lettuce leaves, for the different treatments at the end of the experiment, on the first lettuce crop.

	P (%)	K (%)	Ca (%)	Mg (%)
T0	0.305ab	3.39c	1.94a	2.73a
T1	0.272b	5.88b	5.15a	2.99a
T2	0.243b	7.55ab	1.82a	2.98a
T3	0.197b	8.60a	1.81a	2.98a
T4	0.170b	8.39a	2.44a	2.33ab
T5	0.422a	9.08a	1.64a	1.90b

[1] On each column, average values followed by the same letter do not present significant differences at 95% (multi average comparison - Duncan test). P – phosphorus; K – potassium, Ca – calcium; Mg – magnesium.

In the second crop, the nutrient content of the leaves of lettuce showed the same tendency showed in the previous trial (Table 14).

Table 14 – P, K, Ca and Mg average content[1] in lettuce leaves, for the different treatments at the end of the experiment, on the second lettuce crop.

	P (%)	K (%)	Ca (%)	Mg (%)
T0	0.430b	3.54b	2.71a	5.23a
T1	0.846b	2.14c	2.10ab	4.64ab
T2	1.670a	2.72bc	2,47ab	4.64ab
T3	1.753a	2.71bc	2.17ab	4.73ab
T4	1.863a	3.35b	2.01b	4.39ab
T5	1.856a	4.57a	2.22ab	4.07b

[1] On each column, average values followed by the same letter do not present significant differences at 95% (multi average comparison - Duncan test). P – phosphorus; K – potassium, Ca – calcium; Mg – magnesium.

Regarding micronutrients content of lettuce leaves, no statistical differences were observed between treatments (Table 15). The application of the compost to the soil increased nutrient content [9], which was available for plant development.

Table 15 – Micronutrients (Fe, Cu, Mn and Zn) content in lettuce leaves[1], on the first lettuce crop.

	Fe (%)	Cu (%)	Mn (%)	Zn (%)
T0	0.029a	0.003a	0.018a	0.006ab
T1	0.048a	0.003a	0.016a	0.008a
T2	0.040a	0.002a	0.016a	0.009a
T3	0.041a	0.004a	0.024a	0.005ab
T4	0.036a	0.003a	0.028a	0.006ab
T5	0.022a	0.003a	0.031a	0.005b

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test). Fe – Iron; Cu – copper; Mn – Manganese; Zn – zinc.

In the second crop, Fe and Mn showed higher values in treatment T0. As for Zn, it showed higher values in T5 (Table 16).

Table 16 – Micronutrients (Fe, Cu, Mn and Zn) content in lettuce leaves[1], on the second lettuce crop.

	Fe (%)	Cu (%)	Mn (%)	Zn (%)
T0	0.063a	0.002a	0.022a	0.0060b
T1	0.032b	0.003a	0.018bc	0.0051b
T2	0.024b	0.002a	0.020abc	0.0046b
T3	0.028b	0.002a	0.021ab	0.0043b
T4	0.029b	0.002a	0.017c	0.0050b
T5	0.024b	0.002a	0.018c	0.0084a

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test). Fe – Iron; Cu – copper; Mn – Manganese; Zn – zinc.

F. Soil analysis

Organic matter, pH and the electrical conductivity of the soil saturation paste ECe ($dS.m^{-1}$) at the end of the second lettuce crop are shown in Table 17. Soil organic matter content ranged between 1.76 and 2.78 %. It may be seen that the higher the compost concentration, the higher the organic matter of the soil. The pH slightly increased also with the increase of the compost applied to the soil. Electrical conductivity (ECe) increased with compost dose, ranging between 0.17 and 0.23 dS m^{-1}.

Table 17: Organic matter, pH and electrical conductivity[1] at the end of the second lettuce crop.

	OM (%)	pH	ECe ($dS.m^{-1}$)
T0	1.82cd	8.0b	0.17ab
T1	1.76d	8.2ab	0.12b
T2	2.02bcd	8.3a	0.15b
T3	2.25bc	8.3a	0.18ab
T4	2.34b	8.3a	0.16ab
T5	2.78a	8.3a	0.23a

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test). OM – Organic matter; ECe – Electrical conductivity.

Soil nutrient content at the end of the second lettuce crop are shown in Table 18. Differences between treatments are small, with no clear tendencies, only potassium (K_2O) was higher on the T5 treatment.

Table 18 - Soil Nutrients content[1] at the end of the second lettuce crop.

	N_{total} (%)	N-NH_4^+ (ppm)	N-NO_3^- (ppm)	P_2O_5 (%)	K_2O (%)
T0	0.34a	21.6a	6.33a	0.023ab	0.003c
T1	0.16bc	7.46ab	2.98a	0.022ab	0.005bc
T2	0.33ab	2.24b	2.98a	0.024ab	0.004c
T3	0.24ab	6.71ab	3.36a	0.026a	0.004bc
T4	0.22abc	5.96ab	3.35a	0.022b	0.005b
T5	0.06c	7.45ab	3.73a	0.023ab	0.008a

[1] On each column, average values with the same letter do not present significant differences at 95% (multi average comparison - Duncan test). Total N - total nitrogen; NH_4^+ - ammoniacal nitrogen; NO_3^- - nitric nitrogen; P_2O_5 – phosphorus; K_2O – potassium.

IV. CONCLUSION

Lettuce yield increased with the amount of compost "Organical®" until the maximal tested value - 6 kg m^{-2} (60 t ha^{-1}). However, at this level, there were no statistically differences from growth parameters results obtained with the dose of 3 kg m^{-2} (30 t ha^{-1}).

A faster effect of inorganic fertilization was shown by SPAD readings, subsequently overcome by the effect of compost fertilization on plant growth.

The compost "Organical®" did not show weed contamination, being the higher number of weeds observed on the control treatment. On the contrary, and despite compost maturity, the lower number of weeds on the higher compost treatment suggests some effect on weed control even when compost was incorporated in the soil.

Regarding mineral composition of lettuce leaves, their micronutrient content showed no statistical differences between treatments, except for Zn, being the lower value observed on the treatment with higher compost amount - 6 kg m^{-2}.

Hence, as final remarks, the results have confirmed the validity of the hypothesis that proper fertilization with the compost "Organical" can increase lettuce growth and yield in a sandy soil. However, their positive or negative effects are depending on the best concentration of this compost in the sandy soil. It is suggested the amount of 3 kg m^{-2} (30 t ha^{-1}). For higher compost fertilization doses, some problems might arise, related to a slight increase of soil electrical conductivity, or Pb and Mn excess in lettuce leaves and soil. However, compost may reduce nitrogen losses by leaching, as the slow mineralisation of the compost slowly releases nitrogen to the soil and the crop, avoiding nutrient losses to the soil profile and the aquifers, contributing, therefore, to a saffer environment. Moreover, as the possible destinations of urban sludge and other biosolids (sea, landfilling and incineration) cause environmental problems, their agricultural reuse as "compost" is an opportunity to avoid those problems.

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REFERENCES

[1] Kwon-Rae, K.; Owens, G. 2010. Potential for enhanced phytoremedistion of landfills using biosolids – a review. *Journal of Environmental management*, 91(4):791-797.

[2] Reis, M.; Martinez, F. X.; Soliva, M.; Monteiro, M.M. 1997. Acta Horticulturae, 469:263-274.

[3] Brito, J.M.C.; Lopes, R.; Faleiro, M.L.; Machado, A.; & Beltrão, J.1999. Sewage sludge as a horticultural substratum. In: D. Anaç & P. Martin-Prével (Eds.). Improved Crop quality by Nutrient management, Chapter 47: 205-208. Kluwer Academic Publishers.

[4] Brito, J.M.C.; Coelho, D.; Guerrero, C.A.; Machado, A.V.; & Beltrão, J. 1999. Soil pollution by nitrates using sewage sludges and mineral fertilizers. In: D. Anaç & P. Martin-Prével (Eds.). Improved Crop quality by Nutrient management, Chapter 51: 223-227. Kluwer Academic Publishers.

[5] Guerrero, C.; Faleiro, M. L.; Pita, P.; Beltrão, J.; & Brito, J. 2005. Inorganic and organic Fertilization of "Leeks" cultivated in pots: Yield, Plant mineral Content and Microbial Quality. *European Water* 11/12:9-16.

[6] Guerrero, C.; Pita, P.; Brito, J. 2002. Inorganic and organic fertilization of leeks (Allium porrum) cultivated in pots: soil and leaching chemical properties. *Acta horticulturae*, 573: 83-89.

[7] Costa, M.; Beltrão, J.; Brito, J.; & Dionísio, L. 2008. Effects of manure and sludge application on a citrus orchard. WSEAS Transactions on *Environment and Development* 4(7):567-576.

[8] Brito, J.; Chada, I.; Pinto, P.; Guerrero, C.; Beltrão, J. 2007. Sugar cane pulp residues as a horticultural substratum and as a corrective. NAUN *International Journal of Energy and Environment* 1(2): 75-78.

[9] Cabecinha, A.; Guerrero, C.; Beltrão, J.; & Brito, J.. 2010. Carob residues as a substrate and a soil organic amendment. *WSEAS Transactions on Environment and Development,* 6(5):317-326.

[10] Alvares, I.; Dionísio, L; Guerrero, C.; Brito, J. 2002. The use of aerobic and anaerobic sewage sludges as organic fertilizers in lettuce (*Lactuca sativa*). *Acta horticulturae,* 573: 83-89.

[11] Shiralipour, A.; Mc Connel, B.; Smith ; W. 1992. Uses and benefits of MSW compost: a review and an assessment. *Biomass and Bioenergy*, 3(3-4):267-279.

[12] Costa, M.; Beltrão, J.; Brito, J.; M.; & Guerrero, C. 2011. Turfgrass plant quality response to different water regimes. *WSEAS Transactions on Environment and Development*. 7(6):167-176.

[13] Vermeiren, I; Jobling, G.A. 1980. Localized irrigation, design, installation operation, evaluation. FAO Irrigation and drainage Paper 36, Rome, Italy.

[14] Costa, M.; Beltrão, J.; Brito, J. Neves, M.A.; M.; & Guerrero, C. 2010. The sludge and manure effects on the growth of citrus trees. *WSEAS Transactions on Environment and Development*. 6(11):721-730.

[15] Rubio-Covarrubias, O. A., Brown, P. H. Weinbaum, S. A., Jonhson, R. S., Cabrera, R. I. 2009. Evaluating foliar nitrogen compounds as indicators of nitrogen status in *Prunus pérsica* tress. *Scientia Horticulturae* 120:27-33.

[16] Jesus, S. V., Marenco, R. A. 2008. The SPAD-502 as an alternative to the determination of the chlorofiline content in fruit trees species. *Acta Amazonica* 38 (4): 815-818 (Portuguese).

[17] Young Yeol Ch, Sungbong Oh, Myoung Min Oh, Jung Eek Son. 2007. Estimation of individual leaf area, fresh weight, and dry weight of hydroponically grown cucumbers (*Cucumis sativus* L.) using leaf length, width, and SPAD value. *Scientia Horticulturae* 111: 330–334.

[18] Walkley, A. & Black, I. A. 1934. An examination of the Degtjareff method for determination soil organic and a proposed modification of the chromic acid titration method. *Soil Science* 37: 29-38.

[19] Ramos, J. C. M., Vilaseca, J. S., Ramon, A. C. 1987. Analytical control of the compost quality. p. 31-69. In: Server del Medi Ambient, Diputació de Barcelona (eds). Experiències amb el compost. Estudis I monografies: 12. (Catalan).

[20] Gabriels, R.; Verdonck O. 1991. Physical and chemical characterization of plant substrates: towards a European standardization. *Acta Horticulturae* 294, 249-259.

[21] Lakanen, E. & Ervio, R. 1971. A comparison of eight extractants for determination of plant available micronutrients in soils. *Acta Agralia Fennica* 123:223-232.

[22] Agência Portuguesa do Ambiente. 2008. Technical specifications on the quality and use of the compost. Work document National Proposal. Especificações Técnicas sobre a Qualidade e Utilizações do Composto. Documento de trabalho. Agência Portuguesa do Ambiente, Lisbon.19 pp (Portuguese).

[23] Ferreira, J., Conceição, J., Strecht, A., Ribeiro, J., Soeiro, A., Cotrim, G. 2002. Handbook of bilogical agriculture. – Fertilization on plant protection for a sustainable agriculture. Agrobio. 33rd Edition. Lisbon. pp. 435 (Portuguese).

[24] SPSS 11.0. 2002.SPSS Inc., Chicago, Illinois, U.S.A.
[25] Köppen, W. 1923. Die Klimate der Erde. Walter de Gruyter. Berlin. 388 pp.
[26] Coelho, L., Reis, M. 2011. Effects of the application of the compost to the soil, according to the weeds control. Actas Portuguesas de Horticultura 17. pp: 104-111 (Portuguese).
[27] Almeida, D. 2006. Manual for horticultural crops. Editorial Presença. Volume I. Lisboa. Pp: 158-181. (Portuguese).
[28] Ramakrishna, A., Tam, H.M., Wani, S.P., Long., T.D. 2006. Effect of mulch on soil temperature moisture, weed infestation and tield of groundnut in northern Vietnam. Field crops research 95: 115-125.
[29] Leogrande, R., Lopedota, O., Fiore, A., Vitti, C., Ventrella, D., Montemurro, F. 2013. Previous crops and organic fertilizers in lettuce: Effects on yield and soil properties. Journal of Plant Nutrition 36: 1945-1962.