Stability-associated variation of maturity and plant growth effects of composts

Panagiotis Dalias*[1] and Munoo Prasad [2]

[1] Agricultural Research Institute, Department of Natural Resources and Environment, Nicosia, Cyprus
[2] Compost/AD Research and Advisory, Woodlands Naas, Ireland

*Corresponding author
P. Dalias
Agricultural Research Institute
P.O. Box 22016
1516 Nicosia
Cyprus
e-mail: dalias@ari.gov.cy

Abstract

Purpose

The length of composting is positively related with the stability of compost, negatively related to compost phytotoxicity, and has variable effects on plant growth variables, such as nutrient supply and root conditioning. The work aimed in verifying the notion that the evaluation or ranking of finished composts in relation to stability is indicative to their evaluation or ranking in relation to maturity or plant growth effects.

Methods

This study firstly verified whether there is a relationship between the age of compost and its biological properties using common assays of compost characterization and secondly investigated whether Oxygen Uptake Rate (OUR) estimates of three stable composts of different feedstock composition and the same initial C:N ratio could safely indicate the degree of their phytotoxicity and plant growth promotion.

Results

Results indicated that materials at more advanced stages of composting were more stable, less phytotoxic and immobilized nitrogen after incorporation in soil more intensively than immature composts. However, for composts of different feedstock, stability and phytotoxicity did not correlate as the most stable compost was also the most phytotoxic. In contrast, ranking of materials in relation to plant growth effects coincided with stability, but only after dilution with peat.

Conclusions

An adequate assessment of compost effects on plant germination and growth requires the independent characterization not only of its stability but also its phytotoxicity and nutrient supply capacity, as the three biological properties of compost are often not correlated to each other.

Keywords: compost stability; compost maturity; compost age; oxygen uptake rate; phytotoxicity; plant growth effects

Introduction

Compost market development requires a thorough characterization of compost properties and an association of these properties with its anticipated use. Compost characterization includes a wide range of features. For materials intended to be used in growing media and soil, stability, maturity and nutrient release receive particular attention as they are intimately related to prediction of its impact to plant productivity. These three properties define to a great extent compost quality and potential commercial value [1-3].

Stability is one of the most important compost characteristics. It can be defined as the degree of vulnerability of the material to further decomposition. As such, it is expressed by the magnitude of the decomposing microbial activity, which in turn can be determined by oxygen uptake, carbon dioxide production rate or heat released as a result of this activity [4]. A non-stable material can cause poor plant growth and can contribute to consumers' lack of confidence in the compost product. Aerobic decomposition of organic matter can lead to O_2 depletion if unstable compost is applied to soil resulting in both inadequate oxygen supply to plant roots and reduction in nutrient transfer from soil to plant. Besides agronomic implications, stability is particularly important also for commercial reasons. Stable materials can safely been stored and transported without changes in quality and quantity.

During composting organic compounds are progressively transformed into more stable organic matter and part of carbon is released as CO_2, so by definition, there is a positive relationship of stability with the length of composting [5].

Compost maturity prevailed to refer to the lack of adverse effects of compost on seed germination and plant growth. Phytotoxicity comes from the asphyxiation of roots due to oxygen consumption by the decomposing microorganisms [6], the presence of free ammonia or from the combined effect of several organic intermediates of decomposition such as ethylene oxide and organic acids [7-9].

In relation to the progress of the composting process, Tiquia [10] demonstrated the reduction of phytotoxicity with the progress of composting, since microbial production of toxins is high during the initial decomposition stage and it subsides in the following stabilization stage [11]. Consequently, compost maturity is estimated either directly using various phytotoxicity tests or indirectly, by estimating the degree of decomposition of phytotoxic organic substances produced during the composting process [12].

Another set of biological characteristics refer to those appearing after application of compost to soil or growing media [13]. Although the incorporation of compost is expected to have positive effects on the physical structure and the microbiological activity of plant supporting systems, effects on nutrient supply have been shown not to be straightforward [14]. Very often compost application increases soil Electrical Conductivity (EC), which is almost always a limiting plant growth factor, and induces nitrogen (N) immobilization. From this point of view composts from woody material such as greenwaste are worse than manures and sewage sludge in providing nutrients to plants [15].

The well-documented results that the above biological properties of composts, i.e. stability, maturity and plant growth effects, are related to the progress of composting process and the fact that at least some of their controls are the same (e.g. microbial oxygen consumption for stability and maturity) lead to the intuitive notion that the evaluation or ranking of composts in relation to one property may be indicative of the evaluation or ranking of them in relation to another. However, evidence supporting this hypothesis in not explicit. Oviedo-Ocaña et al. [16] found no correlation between stability and maturity whereas Komilis and Tziouvaras [17] indicated that such correlation existed but it was highly dependent on the kind of seeds used in Germination Index (GI) evaluation. Plant growth effects, which depend on the rate of application, have more rarely correlated with the other biological characteristics. Duong et al. [18], for example, found no correlation between GI and wheat growth effects of compost after compost placement as 2.5 cm thick mulch layer on the soil surface. From the study of a wide range of properties in nine composts of various sources, Paradelo et al. [19] concluded that no single test can be applied to final marketable compost in order to assess maturity and stability and, in particular, that the results of the plant growth tests were not correlated to any other parameter.

This study aimed firstly in showing whether compost stability, phytotoxicity and plant growth effect assays can track differences of composting age and describe the relationship between these characteristics in compost of one feedstock, and secondly indicate whether eventual correlation among them holds on composts from different feedstock.

Materials and Methods

The investigation consisted of two experiments. The first intended to verify that the progression of composting is accompanied by an increase in stability, and associated changes in phytotoxicity and N release potential. Nitrogen release (or immobilization) was chosen to depict effects of compost utilization on plant growth. In this experiment material was sampled from composting material at successive occasions and transferred to the lab for analysis. The second experiment intended to show whether three composts originated from different feedstock mixtures of the same C:N ratio showed the same stability estimates after maturation and if eventual differences in these estimates varied in parallel to phytotoxicity and plant growth estimates.

Production of composts – Analysis of general characteristics

Eight in total turning metal drums of 1.5 m^3 were used for composting. Their axes, on which vertical blades had been welded for better blending of materials, were designed so that they could be attached to a moving motor for periodic turnings. Drums were isolated with stone wool. They were opened for temperature measurements using a portable probe, sampling and water addition.

Turnings were carried out once a week. Water additions were controlled by regular sampling of materials and gravimetric estimations of moisture content. The targeted water content was not the same for all compost types, ranged between 45 and 70%, and was defined empirically so that the material was dumped.

In finished composts pH was measured using EN 13037 [20] and Electrical Conductivity (EC) using EN 13038 [21]. Ash was estimated after organic matter loss on ignition (LOI) at 450°C in a muffle furnace for 12 hours and NO_3^- in 2M KCl extracts after passing them through cadmium reduction columns [22].

First experiment - Compost from the same feedstock at different composting times

Three drums were used to provide the compost (COMP1) for this group of trials. They were filled with municipal tree pruning from lemon, orange, olive, eucalyptus, oleander and acacia trees of unknown proportions. The total mixture which contained small branches and leaves had a C:N ratio of 33. Analyses below referred to material composted for 24, 38, 52 and 67 days.

Analyses

Although stability was measured using the same method at both experiments, tests for phytotoxicity and plant growth effects were selected to be different. In this first experiment, methods were chosen so as to discern the anticipated small differences of the tested materials.

OUR tests

Oxygen Uptake Rate (OUR) estimates were performed using the OxiTop® measuring system (WTW, Wilhelm, Germany) and method EN 16087-1 [23]. Samples varying in weight but containing always 2 g of organic matter were placed in 1 L vessels and diluted with water containing N- allylthiourea as nitrification inhibitor. Due to aerobic microbial activity the oxygen consumption was measured by the pressure heads that were mounted on the vessels. Organic matter content was measured by LOI. The material from each composting age was measured twice and in some cases three times for OUR. The average of these measurements was used in ANOVA.

Phytotoxicity of compost extracts

A 1:5 (w/v) compost:distilled water extract was made for each of the previous composts of different maturity by stirring compost-water mixtures for one hour and filtering using a Whatman 2 paper. Three ml of extract was placed on three sheets of filter paper in each Petri dish and 25 cress seeds were evenly spread on the paper. Three ml of distilled water was used to moisten the filter papers at the control treatments. The Petri dishes were covered to prevent evaporation of the extract and randomly placed in an incubator for 3 days at 25 ± 1°C in darkness (adapted from [24]). Each treatment was replicated three times. Numbers of seeds germinated and their root lengths were recorded. The Germination Index (GI) used was the Munoo – Liisa vitality index (MLV) with the concise formula:

MLV (%) = (GS·RL)*100 / (GSc·RLc) where,

GS and GSc is the average number of Germinated Seeds for sample and control, respectively and RL and RLc is the average Root Length of germinated seeds for sample and control, respectively.

Soil incubations and inorganic N determination

Mixtures of compost with soil were used to estimate its N mineralization potential in controlled moisture and temperature conditions. Composts were removed from the drums at consecutive dates during the composting process as described previously. Soil used was sampled from a wheat field, air dried and sieved with a 2mm sieve. Visible plant residues and roots were removed by hand. This soil had 0.8% organic C content, 0.085% total N, 15% $CaCO_3$, 39% sand and 35% clay.

Incubations of soil + compost mixtures at 25 ± 2ºC were carried out in small plastic 50 ml containers filled with 20 g of soil and 0.1 g of compost material. In order to reduce evaporation water losses, lots of 5-6 containers were enclosed in glass jars with air tight fittings, but with a hole on their lids to allow oxygen replenishment. Water added in containers corresponded to 70% of the WHC of the soil. The amount of mineral N in the soil samples was determined after 10 days from the onset of incubation. Each time, three samples per treatment, were removed from the incubation chamber and soil inorganic N (NH_4^+-N and NO_3^--N) was extracted with 2M KCl. Samples were shaken for 30 min, sieved through No.2 Whatman filter paper and stored frozen. Inorganic N was determined in extracts by colorimetric methods. Nitrate determination involved first the reduction of nitrate to nitrite through a copper-cadmium column, while the estimation of NH_4^+-N was based on the emerald green color formed when ammonia and sodium salicylate react in the presence of sodium hypochlorite.

Second experiment – Three composts from different feedstock

For the production of these composts, the common material used in all drums was tree pruning of *Ficus microcarpa*, which was mixed either with vetch (drums 1, 2, 3, COMP2), goat manure (drums 4, 5, 6, COMP3) or grass clippings (drums 7, 8, COMP4).

To attain a predefined C:N ratio of the initial mixture of feedstocks, plant materials and manure were analyzed for their C and N content. Since these results are necessarily taken on a dry weight basis, the water content and bulk density of each of them were also measured, to express element contents per unit of volume of shredded material. The filling of compost drums was then made using the number of 20 Lt bin loads of each material needed to achieve the C:N ratio of 30:1.

OUR test

Compost stability estimates were made using the OxiTop® system that was described before. Material from each composting drum was measured twice. The average of these measurements was used in ANOVA for differences between composts; three replicates for COMP2 and COMP3 and two for COMP4.

Square Petri dish test with compost

Aiming mainly at the comparison of composts and given that their EC estimates were not very different between them, the square Petri dish test was chosen to be carried out without peat dilution as it is recommended in EN 16086-2 [25] method for compost characterization. Compost materials passed through a 10 mm sieve and moistened to the approximate optimum moisture content according to the fist test. Ten seeds of cress (*Lepidium sativum* L.) were placed at each square Petri dish evenly spaced on a line 15 mm from one edge and pressed gently into the surface of the test material so that there was a good contact with it. A drop of water was also added to each seed using a pipette. As a control, the same procedure was followed for sphagnum peat. The square Petri dishes were placed in an incubator (25 ± 1ºC in the dark) tilted so that roots growing straight down remain visible [26].

The number of germinated seeds was counted and root lengths were measured after 72 h. There were three replications for the material of each of the composting drums. The Germination Index (GI) used was the MLV.

Germination/growth test with compost-peat mixtures and compost only in pots

The test consisted of directly sowing seeds of Chinese cabbage (*Brassica rapa var. Pekinensis*) in composts filling plastic pot trays (35 cm^3 volume) at a rate of 1 seed per pot. Seeds were placed at about 0.5 cm below surface and seed germination was measured after 10 days. The trial was continued to estimate shoot growth after 35 days. A solution with micro and macro nutritional elements was used for watering and fertilizing plants. For each material of a composting drum, 10 pots were filled.

Results

Although the time schedule of measurements during the composting trials was not dense readings showed temperature peaks slightly higher than 60ºC in all drums during the first month of composting. Temperatures then dropped until they reached at about 50 days after the initiation of composting the average air temperatures of the season.

First experiment – Effect of compost age

The maturation of COMP1 was accompanied by an increase in stability and a decrease in phytotoxicity as it was shown by the results of germination trials using compost extracts (Table 1). For the oldest and most stable compost (67-day compost, Table 1) compost extracts appeared to be even phytostimulating at some of the replications.

When composts at different stages of maturity were incubated in soil and at optimum conditions of temperature and moisture the extracted mineral N concentrations showed a decreasing trend (Figure 1). The incorporation of compost in soil resulted always in soil N immobilization, which was greatest for the oldest material.

Second experiment – Composts of different feedstock

Table 2 shows some of the chemical characteristics that were measured in the finished composts after 90 days of composting. All composts were alkaline while the highest value of EC (4.8 dS m^{-1}) was found for COMP2 and the lowest (3.7 dS m^{-1}) for COMP4.

Stability estimates as they were given by the OxiTop® method varied between the three composts (Table 3). They ranged between 4.5 and 12.8 mmol kg^{-1}OM h^{-1} and according to them composts ranked in the following order: COMP3 > COMP4 > COMP2. The most stable compost contained manure as one of the feedstocks. Table 3 indicates also statistically significant difference of means.

Composts showed great phytotoxic effects either when seeds were placed directly on them in square Petri dishes or when they were placed in plant pot trays (Table 3). COMP3 in particular, showed an almost complete restriction of germination.

Initial vegetative development was significantly influenced both by compost type and by mixing with sphagnum peat. In all cases, Chinese cabbage grew more in compost-peat mixtures (1:1, v/v) than in compost only substrates. Among the compost mixtures highest dry biomass yield was shown in COMP3 mixture followed by that at COMP2 and COMP4 (Figure 2) although differences were not statistically significant (P>0.5). COMP3 alone completely inhibited seedling growth till the end of the trial (Figure 2).

Discussion

Stability, phytotoxicity and N mineralization estimates at consecutive times during the course of composting showed that these variables were dynamic. As expected [27], materials that are being composted are becoming more stable and less phytotoxic. Composts at more advanced stages of maturity immobilized N more intensively than immature composts after incorporation in soil presumably due to the elimination of the labile, nitrogen containing substances [28]. Information on N release dynamics of stable and unstable materials in the scientific literature is though inconclusive. Siebert et al. [29], for example, claimed that N dynamics, which is one of the most significant controls of plant growth effects, dependent on the degree of compost stability and that unstable composts can immobilize N. On the contrary, Keeling et al. [2] found than unstable composts release N more than stable ones. Getting insight in these property dynamics may be useful to compost industry where products are probably made by the same initial mixture of feedstock and under the same composting conditions. Depending on market priorities or end uses, composters may seek to stop the composting process at a certain stage with the optimum combination of stability and maturity characteristics. In some cases unstable material has greater positive plant growth effects [30] than mature materials. If this is not compromised by significant increases in phytotoxicity, composters may seek shorter composting periods for acquiring composts with special characteristics.

The results of this part of the study showed, however, that although there is a progressive change of the three variables during the course of composting, the overall characterization of the material based on each of them would not be the same. Relying on O_2 consumption rates, COMP1 after 67 days of composting should be characterized as stable whereas N mineralization results, which indicated significant immobilization, would point to a non-stable material [31]. Regarding the methodological approach it has to be underlined that the OUR method EN 16087-1 [23] was proved to be sensitive enough to track composting age effects on stability.

Contrary to the first part of the study which showed that stability increase during composting is accompanied by phytotoxicity drop and N release restriction, the second part of the work provided rather confounded results. When composts of different feedstocks were compared between them, stability estimates were not indicative of phytotoxicity and vice versa, despite the fact that some characteristics related to feedstock (*Ficus microcarpa* was always present and initial mixture had the same C:N ratio) and composting process (production was carried out in metallic tumblers) were kept the same.

Two of the most essential biological characteristics of compost, stability and phytotoxicity, did not correlate to each other [16, 17, 19]. The most stable compost in this study was shown to be also the most phytotoxic. Microbiologically stable and non-phytotoxic materials are properties related to materials produced at advanced stages of composting but the relationship between the two is such that the one cannot be considered as indicative of the other. It should be taken into account that all composts were characterized as very stable unlike in the first experiment where a number of samples were above 15 mmol $kg^{-1}OM\ h^{-1}$, which is the critical limit value for use of compost in growing media [32]. Comparable results were reported by Blok et al. [33] who found no relation between stability and plant growth when the OUR value was low (< 15 mmol $kg^{-1}OM\ h^{-1}$) but a good relation if the range of values were both high and low. Compost characterization, therefore, should contain both properties for a more comprehensive quality description [34].

Interestingly, mixing composts with peat not only increased seedling growth [35], but also reduced or even removed their phytotoxic effects in such a way as to modify the compost ranking that was based on GI values (Figure 1). Apparently, either the dilution of chemical substances affecting toxicity or increased microbial degradation of them caused an important reduction of the negative effects of compost on plant growth [36]. Hence, moistening compost for a sufficient period of time and chemical dilution should be considered as necessary conditions to uncover plant growth effects and to allow eventual plant growth promoting agents in it to be manifested. Consequently, full characterization of compost, apart from stability and maturity, requires estimates of plant growth effects after moistening substrate for sufficient time or dilution of compost or other treatment so that the adverse effects of phytotoxicity have been waived. In this study plant growth effects were revealed after one month of seedling growth. Moreover, current results indicated that growth effects were at the same direction as stability estimates would imply, i.e. the more stable composts were also the more plant growth stimulating.

Acknowledgements

The authors would like to thank M. Elia and T. Louka for technical assistance.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

[1] Grebus, M.E., Watson, M.E., Hoitink, H.A.J.: Biological, chemical and physical properties of composted yard trimmings as indicators of maturity and plant disease suppression. Compost Sci. Util. 2, 57-71 (1994)

[2] Keeling, A,A., Griffiths, B.S., Ritz, K., Myers, M.: Effects of compost stability on plant growth, microbiological parameters and nitrogen availability in media containing mixed garden-waste compost. Bioresour. Technol. 54, 279-284 (1995)

[3] Bernal, M,P., Navarro, A.F., Sanchez-Monedero, M.A., Roig, A., Cegarra, J.: Influence of sewage sludge compost stability and maturity on carbon and nitrogen mineralization in soil. Soil Biol. Biochem. 30, 305-313 (1998)

[4] Komilis, D., Kletsas, C.: Static respiration indices to investigate compost stability: Effect of sample weight and temperature and comparison with dynamic respiration indices. Bioresour. Technol. 121, 467-470 (2012)

[5] Lasaridi, K.E., Stentiford, E.D.: A simple respirometric technique for assessing compost stability. Water Res. 32, 3717–3723 (1998)

[6] Brinton, W.F., Evans, E.: How Compost Maturity Affects Container Grown Plants. Biocycle 42, 56-60 (2001)

[7] Wong, M.H.: Phytotoxicity of refuse compost during the process of maturation. Environmental Pollution Series A, Ecological and Biological 37, 159-174 (1985)

[8] Jiménez, E.I., Garcia, V.P.: Evaluation of city refuse compost maturity: a review. Biol. Wastes 27, 115-142 (1989)

[9] Foster, J.C., Zech, W., Wurdinger, E.: Comparison of chemical and microbiological methods for the characterization of the maturity of composts from contrasting sources. Biol. Fertil. Soils 16, 93-99 (1993)

[10] Tiquia, S.M.: Reduction of compost phytotoxicity during the process of decomposition. Chemosphere 79, 506-512 (2010)

[11] Zucconi, F., Monaco, A., Forte, M., de Bertoldi, M.: Phytoxins during the stabilization of organic matter. In: Glasser, J.K. (ed) Composting of Agricultural and other Wastes, pp.73–85. Elsevier Applied Science, London (1985)

[12] Wu, L., Ma, L.Q., Martinez, G.A.: Comparison of methods for evaluating stability and maturity of biosolids compost. J. Environ. Qual. 29, 424-429 (2000)

[13] Prasad, M.: A literature review on the availability of nitrogen from compost in relation to the nitrate regulations SI 378 of 2006. EPA STRIVE Programme 2007-2013. Environmental Protection Agency of Ireland, Small Scale Study Rept., Co Wexford (2009)

[14] Gale, E.S., Sullivan, D.M., Cogger, C.G., Bary, A.I., Hemphill, D.D., Myhre, E.A.: Estimating plant-available nitrogen release from manures, composts, and specialty products. J. Environ. Qual. 35, 2321-2332 (2006)

[15] Gagnon, B., Simard, R.R.: Nitrogen and phosphorus release from on-farm and industrial composts. Can. J. Soil Sci. 79, 481-489 (1999)

[16] Oviedo-Ocaña, E., Torres-Lozada, P., Marmolejo-Rebellon, L., Hoyos, L., Gonzales, S., Barrena, R., Komilis, D., Sanchez, A.: Stability and maturity of biowaste composts derived by small municipalities: Correlation among physical, chemical and biological indices. Waste Manage. 44, 63-71 (2015)

[17] Komilis, D.P., Tziouvaras, I.S.: A statistical analysis to assess the maturity and stability six composts. Waste Manage. 29, 1504–1513 (2009)

[18] Duong, T.T.T., Penfold, C., Marschner, P.: Amending soils of different texture with six compost types: impact on soil nutrient availability, plant growth and nutrient uptake. Plant Soil 354, 197–209 (2012)

[19] Paradelo, R., Moldes, A.B., Prieto, B., Sandu, R-G., Barral, M.T.: Can Stability and Maturity Be Evaluated in Finished Composts from Different Sources?, Compost Sci Util. 18, 22-31 (2010)

[20] EN 13037: Soil improvers and growing media – Determination of pH. CEN. European Committee for Standardization, Brussels (1999)

[21] EN 13038: Soil improvers and growing media – Determination of electrical conductivity. CEN. European Committee for Standardization, Brussels (1999)

[22] Keeney, D.R., Nelson, D.W.: Nitrogen-inorganic forms. In: Page, A.L., Miller, R.H., Keeney, D.R. (eds.) Methods of Soil Analysis. Part 2 – Chemical and microbiological properties, pp. 643-698. Agronomy Monograph no. 9 (1982)

[23] EN 16087-1: Soil improvers and growing media - Determination of the aerobic biological activity - Part 1: Oxygen uptake rate (OUR). CEN. European Committee for Standardization, Brussels (2012)

[24] Zucconi, F., Forte, M., Pear, A., DeBertoldi, M.: Evaluating toxicity of immature compost. Biocycle 22, 54-57 (1981)

[25] EN 16086-2: Soil improvers and growing media - Determination of plant response. Part 2: Petri dish test using cress. CEN. European Committee for Standardization, Brussels (2011)

[26] Prasad, M., Baumgarten, A., Grünstäudl, U., Ni Chualain, D.: Recent developments in the measurement of stability and maturity of compost in Europe. In: Orbit 2010, Heraklion. Proceedings of the 7th International Conference, 29 June-3 July 2010, pp. 998–1003. Crete (2010)

[27] Aslam, D.N., VanderGheynst, J.S.: Predicting phytotoxicity of compost-amended soil from compost stability measurements. Environ. Eng. Sci. 25, 72-81 (2008)

[28] Griffin, T.S., Hutchinson, M.A.R.K.: Compost maturity effects on nitrogen and carbon mineralization and plant growth. Compost Sci. Util. 15, 228-236 (2007)

[29] Siebert, S., Leifeld, J., Kögel-Knabner, I.: Stickstoffmineralisierung von Bioabfallkomposten unterschiedlicher Rottegrade nach Anwendung auf landwirtschaftlich genutzte und rekultivierte Böden. Z. f. Kulturtechnik und Landesentwicklung 39, 69-74 (1998)

[30] Keeling, A.A., Paton, I.K., Mullett, J.A.: Germination and growth of plants in media containing unstable refuse-derived compost. Soil Biol. Biochem. 26, 767-772 (1994)

[31] Sesay, A.A., Lasaridi, K., Stentiford, E., Budd, T.: Controlled Composting of Paper Pulp Sludge Using the Aerated Static Pile Method. Compost Sci. Util. 5, 82-96 (1997)

[32] Foster, P., Prasad, M.: To develop national end of waste standards for quality compost and digestate. Report 2018-RE-DS-10, p. 89. Environmental Protection Agency (Ireland) (2020)

[33] Blok, C., Baumgarten, A., Baas, R., Weever, G., Lohr, D.: Analytical Methods used with soilless substrates. In: Raviv, M., Leith, J.H., Bar-Tal, A. (eds.) Soilless Culture, pp. 509-564. Academic Press Inc, London (2019)

[34] Cooperband, L.R., Stone, A.G., Fryda, M.R., Ravet, J.L.: Relating compost measures of stability and maturity to plant growth. Compost Sci Util. 11, 113-124 (2003)

[35] Tittarelli, F., Rea, E., Verrastro, V., Pascual, J.A., Canali, S., Ceglie, F.G., Trinchera, A., Rivera, C.M.: Compost-based nursery substrates: effect of peat substitution on organic melon seedlings. Compost Sci. Util. 17, 220-228 (2009)

[36] Dalias, P., Prasad, M., Mumme, J., Kern, J., Stylianou, M., Christou, A.: Low-cost post-treatments improve the efficacy of hydrochar as peat replacement in growing media. J. Environ. Chem. Eng. 6, 6647-6652 (2018)

Figure captions

Figure 1: Net immobilization of nitrogen in μg of mineral-N (NH_4^+-N + NO_3^--N) per g of dry soil obtained after 10-day incubation of soil mixed with COMP1 that was sampled at various dates during the composting process. Columns with the same letter are not significantly different (Tukey's post-hoc test, P>0.05).

Figure 2: Average production of Chinese cabbage (g/plant) grown in pot trays, using as a substrate either equal volumes of compost and sphagnum peat or only compost. Columns with the same letter are not significantly different (Tukey's post-hoc test, P>0.05).

Table 1: Results of the O_2 consumption rate (OUR in mmol kg^{-1}OM h^{-1}) measured by the OxiTop® device, MLV index using compost extract, pH and EC of COMP1 at different stages of the composting process.

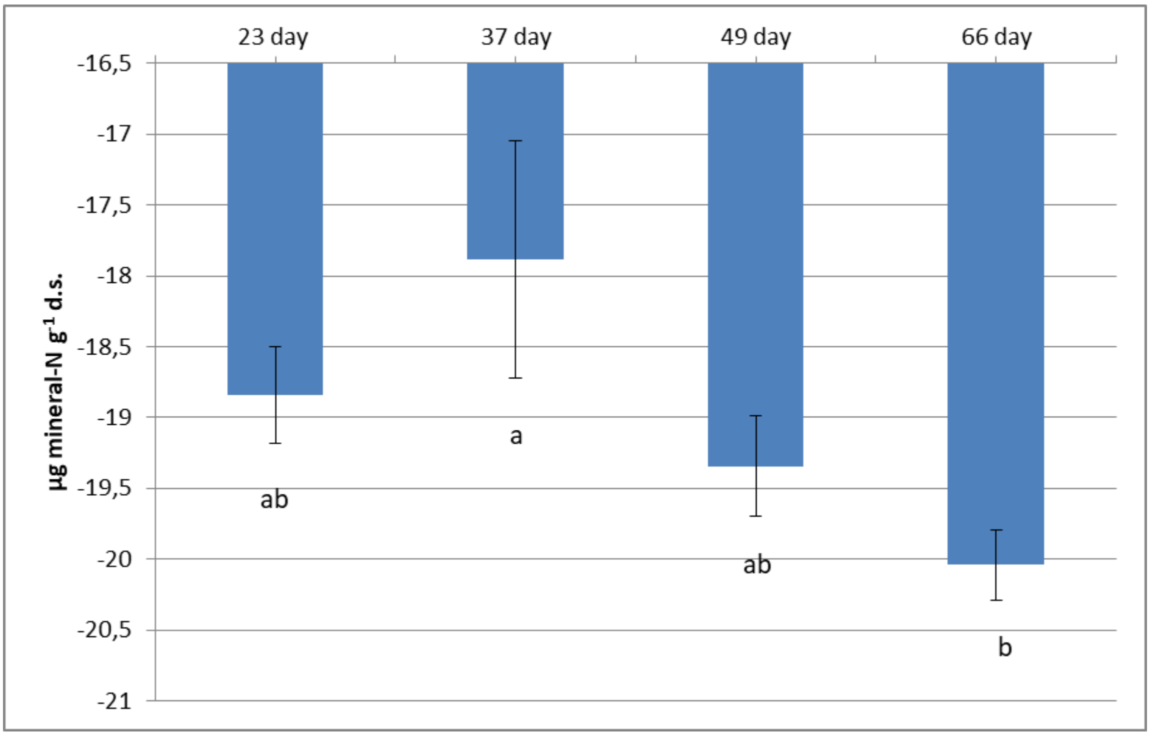
Days of composting	**OUR** Mean ± SEM			**MLV extract** Mean ± SEM			**pH**	**EC**
24	25,21	±0,42	a	0,76	±0,04	a	8,9	3,05
38	21,84	±0,33	b	0,87	±0,01	ac	8,6	3,20
52	16,61	±0,54	c	0,96	±0,00	bc	8,7	3,20
67	14,27	±0,03	c	1,18	±0,07	d	8,4	3,40

Table 2: Some of the chemical characteristics of the composts used at the stability, maturity and plant growth trials.

	EC	**pH**	**NO_3^-**	**Ash**
	dS m^{-1}		mg kg^{-1}	%
COMP2	4,8	8,9	1450	24,35
COMP3	4,2	8,8	300	57,80
COMP4	3,7	8,3	925	46,40

Table 3: Results for stability and maturity characterization of the three composts as it is manifested by O_2 consumption (OUR) measured by the OxiTop® device, MLV indices measured using the square Petri dish test, and % seed germination given by pot tray trials. Numbers indicate mean values ± SEM. When followed by the same letter are not statistically different (Tukey's post-hoc test, *P*>0.05).

	OUR Mean ± SEM		MLV index Mean ± SEM		% seed germination	
COMP2	12,78	±1,70 a	7,45	±2,94 ab	33,33	±9,62 ab
COMP3	4,49	±0,30 b	0,78	±1,18 a	5,56	±5,56 a
COMP4	10,48	±0,52 a	15,88	±4,50 bc	75,00	±25,00 bc



23 day
37 day
49 day
66 day
-16,5
-17
-17,5
-18
-18,5
-19
-19,5
-20
-20,5
-21
µg mineral-N g-1 d.s.
ab
a
ab
b

Figure 1

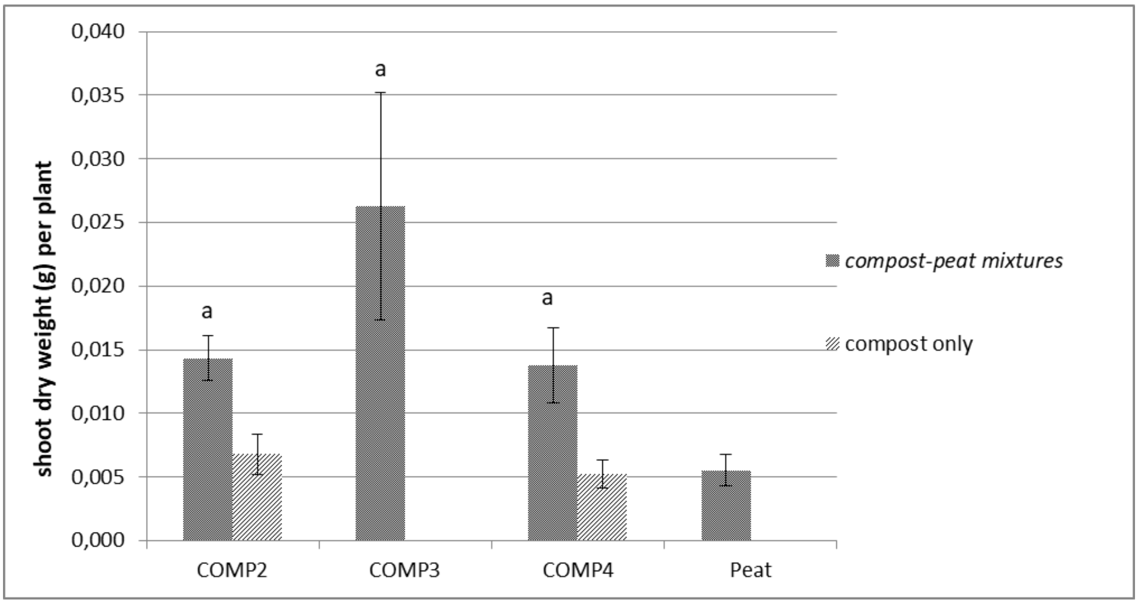

0,040
0,035
0,030
0,025
0,020
0,015
0,010
0,005
0,000
shoot dry weight (g) per plant
a
a
a
COMP2
COMP3
COMP4
Peat
compost-peat mixtures
compost only

Figure 2