Future of compost as an alternative to chemical compounds in ecological agriculture

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Abstract

Composting is a traditional method of waste treatment that means a stabilization of organic matter to be applied to soil. Compost is used in soils as organic amendments but it is necessary to find new properties for compost to increase its value. One research field that is increasing is its potential use to control plant pathogens, giving an important value as biofertilizers and biopesticides in ecological agriculture where no chemicals can be used. Our research is focused on the potential action of compost as an alternative to chemical disinfection with methyl bromide by biofumigation-solarization (application of fresh compost to soil covering with a plastic, and leaving to raise soil temperature); it is also shown that the green compost controls fusiarosis wilt on melon plants, demonstrating that the effect is caused by biotic and abiotic factors. Future trends are also commented, where it is necessary to delve into the potential uses of compost because it is necessary to develop new demands to open markets for compost, demonstrating their beneficial effects on many aspects such as biofertilizers, biopesticides, etc.

Keywords: biofertilizers, biopesticide, composting process, biofumigation, solarization, plant pathogens.

1 Present and future of compost

The European Community policy is to reach the zero waste and this is obliging to reutilize the different wastes. The organic waste has to be reutilized by their use in agriculture, converting it from waste to resource. The most important pool of organic waste are from agriculture (80%) and the urban life (10%). The organic matter from different waste can be used as organic amendments but it is necessary to stabilize them by composting process. The composting process is a
biodextrative process with a termophilic phase giving as a result an stabilised product denominated compost free of weeds and pathogens. There is many papers on the effect of compost on soil and plant quality. These studies can be summarized in the way that compost from different origins alters physical, physical-chemical, chemical and biological properties of the amended soils [12]. The organic matter content from compost educes the apparent density of a soil, providing it with greater sponginess, positively influencing aggregate formation and stability and increasing its WHC so that it can better resist droughts. It increases the OM content, mainly phosphorus and nitrogen, gradually releasing them and making compost more effective than inorganic fertilisers. The addition of compost to a soil encourages increased microbial growth due to the improvement in the soil's physical and chemical properties. Thus, plants developed on amended soils would need less amounts of chemical fertilizers, obtaining better results. Therefore compost can be used as organic amendments in agriculture and also to remediate low organic matter soils.

In Spain, compost are underused in agriculture because farmers does not trust in their effect, but new types of soil use such as ecological agriculture where no chemical can be used is giving a main role to organic products such as compost. If it is necessary to use on drip irrigation is necessary to use them in new ways: liquid or localized amendment under the drip system. In ecological agriculture, the important point of compost is that they has to come from natural origin, thus means that only green compost can be used. Furthermore, the compost in ecological agriculture can play the important role to act as biofertilizers because no chemicals can be used. Other of the ecological agriculture premises is the forbidden to use chemical pesticides to control pests. Recently, compost has been demonstrated that can improve soil’s resistance to pests and diseases caused by pathogenic organisms. This new aspect can again gives the central point to the development of ecological agriculture.

Some compost made from agricultural wastes have been used to control *Fusarium* (typical pathogens of cereal diseases). A decrease in *Fusarium* is correlated with an increase in *Trichoderma*, which is incorporated with the organic material [6]. *Phytophthora*, another pathogenic fungus with a wide action spectrum (root rot, red heart in strawberry and mildew in tomato, apple and strawberry etc.) can also be controlled by using agricultural dosage levels of compost. Sewage sludge composts have been used to control *Sclerotinia* in lettuce, tomato, rape etc., while composts from timber industry waste has been assayed with broad spectrum fungi like *Fusarium, Phytophtora* and *Rhizoctonia*.

Peats have been widely used as organic substrate for cultivating ornamentals, one of its most favoured properties being its capacity to protect against certain pathogens. Recent years, though, have seen a decline in its use because resources are running out and being replaced by cheaper compost made from vegetal wastes.

## 2 Pest and disease control by compost

There are several, interrelated factors, which, although difficult to separate, can be put into two major groups, as follows.
2.1 Biological factors

Numerous microorganisms that have been demonstrated its effects on controlling some soil diseases are usually found in compost. Among this group of microorganisms, we might mention fungi of the genus *Trichoderma*, *Penicillium* and *Gliocadium*, which are capable of growing and developing in all types of environment, especially those rich in compounds which cannot easily be used by other microorganisms, such as lignocellulose wastes. Some groups of bacteria, such as *Bacillus subtilis*, *B. thurigiensis*, *B cereus*, *B mycoides*, *Pseudomonas fluorescens*, *P putida*, *Xanthomonas maltophilia*, *Enterobacter cloacae* etc., are also characteristic of stable organic materials, many of them due to their capacity to withstand high temperatures. The presence of this type of microorganism in a compost, therefore, makes it a candidate for use in the control of pathogens [19].

Disease suppression is also correlated with the increased microbial activity after the addition of the compost to the soil. This disease suppression may also be correlated with the improved nutritional status of the soil treated with compost, which translates into an improvement in the plant immune system [6].

2.2 Physical chemical factors

There are also physical or chemical factors included on compost that can be the responsible for the suppression activity. In nursery experiments, oxygen values of around 25% and percolation rate in excess of 2.5cm/min suppressed *Phytophthora*, a fungal pathogen of wide spectrum, which shows optimal growth below 15% oxygen. The change of 1 level on the pH could be enough to reduce the formation sporangi and the release of zoospores, avoiding the spread of plant pathogens *Phytophthora* and *Fusarium sp*. Particle size, lignin and cellulose content, electrical conductivity and pH are all decisive factors in a compost’s capacity to act as biocontrol since their values will decide on the pathogen’s establishment in the soil or not.

3 Use of compost for ecological agriculture

The use of compost in ecological agriculture as biofertilizer and biological control against plant diseases can give a new dimension to the waste management. Compost will acquire an important role, improving the ecological agriculture. It has to be exposed some research developed where compost can be utilized as alternative to methyl bromide for cleaning soils before planting pepper plants, use of green compost to control Fusarium oxysporium in melon, and also some new research to manipulate composting process to improve its effect as biological control of plant diseases.

3.1 Compost in biofumigation-solarization as alternative of methyl bromide

Biofumigation-solarization of soils is a disinfection system that is used against plant pathogens as an alternative to methyl bromide. Soil biofumigation-solarization is a non-chemical approach to soil disinfestation. Pathogen control is
accomplished by compost from agriculture wastes amended to soil (biofumigation) and covering the soil surface with a clear plastic film to trap solar radiation and accumulate heat (solarization). In this way, soil temperatures can be raised to levels that are lethal to many plant pathogens (Figure 1). The main mechanism is the direct thermal inactivation of soil borne pathogens and pests. The levels of ammonium are also increased as a consequence of mineralization of the organic materials that are rich in organic nitrogen (Table 1). The concentration of many volatile compounds emanating from organic matter decomposition or mineralization within the soil has also been shown to be significantly higher [4]. The soil temperatures achieved in this study were within the range of temperatures reported in other studies. This synergism between solarization and organic amendment has been documented by many authors as producing better results than soil solarization or organic amendments individually [4].

This experiment was carried out for five years, incorporating a new plot each year, taken soil samples the last year, having, therefore, soil samples from different years of biofumigation-solarization: (b1) one year of biofumigation (started year 4); (b3), three years of biofumigation (started year 2); (b4) four years of biofumigation (started year 1) and (b5) five years of biofumigation (started year 0). During the first years of the organic amendments, the initial levels of organic matter applied were higher than the usual level used as organic amendment by local growers because it was looking for an initial shock against plant pathogens, as described in the literature [4]. An important point in this research was the gradual decrease in the dose of organic amendment applied each year to reach the usual dose used by growers, without losing the initial effect as plant pathogen control. The assay was carried out in triplicate random plots, which were treated with organic amendment and solarization (biofumigation-solarization), or methyl bromide at 30 g m\(^{-2}\) with a virtually impermeable film (VIF). A soil receiving no treatment was used as control.

Every year, biofumigation-solarization was started during the last week of August and the plastic was maintained until early November. Methyl bromide was applied in mid November and pepper plants were planted in early January. The pepper fruits were collected in early-mid August. Soil sampling was carried out: (1) before biofumigation-solarization and previous applying the new fresh organic matter for the biofumigation, when the plants of the previous cultivate had been removed from the soil (20\(^{th}\) of August 2001), (2) after biofumigation-solarization or methyl bromide application, (1\(^{st}\) of December 2002) and (3) at the end of cultivation before removing plants (16\(^{th}\) of August 2002).

Pepper production was significantly reduced when no treatment was applied, a point that emphasises the need of finding an appropriate system of soil disinfection [3, 4, 9]. The biofumigation-solarization of soil maintained the same or little bit greater level of total production as methyl bromide treatment (Table 1). The number of years of biofumigation-solarization did not significantly affect the production of pepper. From an economic point of view, therefore, the use of biofumigation-solarization can be considered a real alternative to methyl bromide in both the short and long-term. It can be pointed
out that the biofumigation-solarization tends to encourage greater production and quality than methyl bromide, because the incorporation of organic materials improves soil physical properties, nutritional status and the stimulation of beneficial microorganisms such as fluorescent pseudomonad bacteria in the soil solution [3].

It is also noticeable that the progressive reduction in the amount of organic matter added for biofumigation-solarization each year had no negative effect on plant production, meaning that this practise can be considered suitable for controlling plant pathogens, the soil adapting from methyl bromide to biofumigation solarization treatment. Some studies have suggested the initial level of organic matter should be around 10 Kg m\(^{-2}\) to be effective as disinfectant [2]. This amount was applied in this study, but once the soil was disinfested, was maintained by applying gradually decreasing amount of organic matter each season, to reach the levels of organic matter that are usual for growing pepper plants. Therefore, if this application is made at the correct time in conjunction with the solarization, the application can have two objectives: disinfection and organic amendment.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Extra</th>
<th>First class</th>
<th>Second class</th>
<th>Third class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>7.82</td>
<td>0.45</td>
<td>2.32</td>
<td>3.60</td>
<td>1.35</td>
</tr>
<tr>
<td>MeBr</td>
<td>9.27</td>
<td>0.54</td>
<td>2.76</td>
<td>4.48</td>
<td>1.31</td>
</tr>
<tr>
<td>B1</td>
<td>10.16</td>
<td>0.71</td>
<td>3.42</td>
<td>4.72</td>
<td>1.12</td>
</tr>
<tr>
<td>B3</td>
<td>10.19</td>
<td>0.73</td>
<td>3.61</td>
<td>4.72</td>
<td>1.00</td>
</tr>
<tr>
<td>B4</td>
<td>9.68</td>
<td>0.57</td>
<td>3.41</td>
<td>4.55</td>
<td>1.04</td>
</tr>
<tr>
<td>B5</td>
<td>10.30</td>
<td>0.65</td>
<td>3.60</td>
<td>4.87</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Least significant differences at P\(\leq 0.05 = 0.60\); Extra: > 90 mm (> 220g); First class: 80-89 mm (180-220 g); Second class 70-79 mm (120-179 g); Third class: 60-69 mm (85-119 g).

It is necessary to establish whether this new tool for cleaning and disinfecting soils can be used as a real alternative to chemical fumigants and also to establish its effect on short and long-term soil quality. Biological and biochemical properties are responsible for small changes that occur in soil, thereby providing immediate and accurate information on changes in soil quality.

ATP is a bioindicator of microbial biomass when soil is incubated in optimal conditions after taking soil from the field [10]. Fumigation with methyl bromide produced a reduction in the content of ATP, that was maintained at the different sampling times, meaning that the biocide effect of methyl bromide is not specific to pathogen microorganisms but irreversibly affects natural microbial populations (Figure 1). Biofumigation-solarization also produced a decrease in the ATP content, but this-recovered with time to reach the initial values. The number of years of biofumigation-solarization did not affect the ATP content, which was always higher with this treatment than in the methyl bromide treated and after cropping was also higher than in the control soil (Figure 1).
This means that methyl bromide not only provokes the immediate death of microbial biomass, but that there is no recovery with time due to the hypotheses mentioned above: residual methyl bromide is trapped in the soil producing long-term negative effect on soil. In any case, it is clear that methyl bromide besides having a long-term negative effect on human and environmental health, also has a negative action on the microbial biomass of a soil and can therefore cause a decrease in soil quality that it is not easily recovered. The biofumigation-solarization step also decreased microbial biomass, although to a significantly lower extent than when methyl bromide was used (Figure 1). This suggests that biofumigation-solarization can also act as biocide, killing harmful pathogens, which are extremely sensitive to high temperatures [17], but does not greatly affect the natural microorganisms, which remain at significantly higher level than when the chemical fumigant was used [17].

Figure 1: ATP content of the differently treated soils (Least significant differences at P £ 0.05 =10).

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level than when the chemical fumigant was used [17]. The main and most important difference between biofumigation-solarization and methyl bromide treatment was that the level of microbial biomass was recovered by the end of the crop season with the former treatment, while the inhibition of microbial biomass remained with the latter treatment (Figure 1). It was also demonstrated that the use of biofumigation-solarization in successive years does not have a negative effect on microbial biomass or on any of the above parameters measured. Furthermore, if the content of ATP is compared with others treatments, it can be seen that the microbial biomass is higher than in the control and the soil treated with methyl bromide (Figure 1). This fact demonstrates the better maintenance of soil microbial quality in biofumigated-solarized soils than in the non treated soil or after chemical application (Figure 1). For these reasons, biofumigation-solarization can be considered a real alternative to methyl bromide since maintains production, implying the same level of pathogen elimination. It has no toxic effect on soil and not only does it have no negative effect on soil microbial biomass, but actually increases, which represent an improvement of soil microbiological quality.

3.2 Use of green compost to control *Fusarium oxysporum* in melon

The suppressive effect against *Fusarium* wilt of a semiarid agricultural soil amended with green composts made by the Indore composting method was demonstrated. The localisation of this suppressiveness and attempt to ascertain whether it is of a biotic or abiotic nature was also attempted. At the same time, the maintenance or increase in the quality or fertility on agricultural soils amended with these composts is demonstrated.

A *Fusarium* sp contaminated soil was amended with different green composts: compost A, mixture of pine bark and urea (1000/1 w/w); compost B, a mixture of pruning wastes and coffee wastes (3/1 w/w); compost C, a mixture of pruning wastes and coffee wastes (4/1 w/w) and compost D, mixture of pruning wastes alone. Composting was carried out in piles with periodical turning (Indore method) over a period of 8 months in the case of composts A, B and C and 12 months in the case of compost D with no added nitrogen source. After composting, the composts were left untouched in static piles for 3 months to complete the maturation process.

The characteristics of these materials permit us to describe them as useful organic amendments with a degree of fertilising value (Table 2) since they improve the soil's structure, physical-chemical and nutritional status and microbiological activity [5]. The biological activity of these materials is considerably higher than that of the soil, as can be seen from the grater number of fungi, bacteria and biochemical activity (Table 3). Their addition to the soil, therefore, may improve the biological activity for two reasons: the biological activity generated during composting is transferred to the soil or the biogeochemical cycles of the soil are reactivated by the incorporation of easily biodegradable compounds [11, 12, 13, 14].

The ability of green composts to vary both the microbial activity of the soil and its physical, chemical and physico-chemical properties may favour or hinder
the adaptation of certain microorganisms over others [1], which might be an important factor in the influence of green composts on the effect of pathogenic microorganisms such as *Fusarium oxysporum*.

### Table 2: Chemical characteristics of the green composts.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Compost A</th>
<th>Compost B</th>
<th>Compost C</th>
<th>Compost D</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (H₂O, 1:10)</td>
<td>5.9</td>
<td>8.4</td>
<td>8.1</td>
<td>8.1</td>
</tr>
<tr>
<td>Electrical conductivity (dS cm⁻¹)</td>
<td>0.21</td>
<td>1.59</td>
<td>1.49</td>
<td>1.13</td>
</tr>
<tr>
<td>Total organic carbon (g kg⁻¹)</td>
<td>300.1</td>
<td>161.7</td>
<td>201.3</td>
<td>244.4</td>
</tr>
<tr>
<td>Water soluble carbon (g kg⁻¹)</td>
<td>6.33</td>
<td>4.55</td>
<td>4.66</td>
<td>5.87</td>
</tr>
<tr>
<td>Total organic matter (g kg⁻¹)</td>
<td>964</td>
<td>531</td>
<td>633</td>
<td>836</td>
</tr>
<tr>
<td>Total N (g kg⁻¹)</td>
<td>8.6</td>
<td>12.7</td>
<td>16.9</td>
<td>9.0</td>
</tr>
<tr>
<td>Total P (g kg⁻¹)</td>
<td>0.07</td>
<td>2.07</td>
<td>2.13</td>
<td>0.07</td>
</tr>
<tr>
<td>Total K (g kg⁻¹)</td>
<td>2.6</td>
<td>11.3</td>
<td>11.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Ratio C/N</td>
<td>34.9</td>
<td>12.7</td>
<td>11.9</td>
<td>27.1</td>
</tr>
</tbody>
</table>

### Table 3: Microbiological and biochemical characteristics of the green composts.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Compost A</th>
<th>Compost B</th>
<th>Compost C</th>
<th>Compost D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria (log₁₀ cfu ††) g⁻¹</td>
<td>8.18</td>
<td>8.27</td>
<td>8.78</td>
<td>8.78</td>
</tr>
<tr>
<td>Fungi (log₁₀ cfu ††) g⁻¹</td>
<td>5.58</td>
<td>6.68</td>
<td>5.56</td>
<td>4.66</td>
</tr>
<tr>
<td>Phosphate activity</td>
<td>4.03</td>
<td>34.31</td>
<td>19.88</td>
<td>20.06</td>
</tr>
<tr>
<td>(µmol PNP g⁻¹ h⁻¹)</td>
<td>0.82</td>
<td>7.88</td>
<td>5.04</td>
<td>6.48</td>
</tr>
<tr>
<td>β-Glucosidase activity (µmol PNP g⁻¹h⁻¹)</td>
<td>0.6</td>
<td>0.23</td>
<td>0.29</td>
<td>0.31</td>
</tr>
<tr>
<td>Urease activity</td>
<td>0.6</td>
<td>0.23</td>
<td>0.29</td>
<td>0.31</td>
</tr>
</tbody>
</table>

The incorporation of the green composts into the soil lowered the incidence of *Fusarium oxysporum* in melon plants, increasing the yield compared with unamended soil (Figure 1) and demonstrating the biopesticide value of this type of material for use against *Fusarium oxysporum* in melon. The pathogen showed a 60% incidence on the plant melon in the control soil, which fell to 11-23% in the soil amended with compost (Figure 2), probably due to the changes in the biotic and abiotic properties produced by the incorporation of the green composts. Part of this biopesticide effect has already been demonstrated in this study by reference to the direct action of the composts against the pathogen, but
it was necessary to study its incidence in soil since the establishment of the pathogen in soil can be avoided by indirect causes that are not contemplated in the last experiment such as microorganisms from compost can be established in the pathogen niches or soil conditions could be changed as consequence of compost amended that could not be adequate for the plant infection by the pathogen. From this study, it can be concluded that the suppressiveness of compost against *Fusarium oxysporum* is due to the introduction of antagonist microorganisms or the indirect effect of compost to increase the natural antagonist microorganisms from soils [19].

Indeed, green composts are characterised by their great variety of substrates, permitting an equally large variety of microorganisms to become established, of which some are capable of participating in the control of diseases like *Fusarium* wilt [14]. Their potential is as much a function of their density as composition [7], and it has been demonstrated that combinations of microorganisms, such as may occur in soils amended with green composts, may be more effective than when the microorganisms act individually.

Fungal and bacterial microorganisms were isolated from the green composts and their effect against *Fusarium oxysporum* was tested confronting them with the pathogen in a Petri, studying their behaviour, concluding that in general green composts may be considered for use in controlling soil-borne diseases, such as *Fusarium* wilt in melon. Despite the wide range of biocontrol effects, it is clear that the fungi present a greater degree of biological control against the pathogen than the bacteria. The isolated fungi basically showed two action mechanisms: micoparastism, involving direct contact between both microorganisms (antagonist-pathogen) on the plate and subsequent antagonist growth to reduce the pathogen and the production of antibiotic-type secondary metabolites, which spread through the medium, leaving a clear band that separates the antagonist from the pathogen [7]. The bacteria, on the other hand, only showed this second mechanism of antibiotic production. The *in vitro* experiments showed that composts A (mixture of pine bark and urea) and B (mixture of pruning wastes and coffee wastes 3/1 w/w) inhibited *Fusarium oxysporum* growth to a greater extent than the other two composts, the action of the fungi being noticeably more intense than that of the bacteria isolated.

*In vitro* experiments, growing the plant pathogen on sterile compost was also carried out to establish any relation between the abiotic factors of the green composts and *Fusarium oxysporum* growth and development. The fact that only compost A (mixture of pine bark and urea) did so, was probably mainly due to its lower pH, which would have immobilised some compound necessary for the pathogenicity, although the bibliography suggests that is composts B, C and D that show the characteristics necessary for potential abiotic action against the pathogen. These include a basic pH that would reduce the availability of micronutrients, such as iron, copper and zinc, thus limiting *Fusarium oxysporum* sporulation and a high EC values, which would reduce the pathogen's survival. It is possible that the abiotic factors were not sufficient in the *in vitro* experiment to have a direct effect on pathogen development, but would be so once the composts were added to the soil, since the same abiotic factors may provide the
ideal environment for increasing the microbial populations necessary for controlling *Fusarium oxysporum*. If this is so, the abiotic factors of green composts would be responsible for controlling the pathogen indirectly since they would encourage the growth of microorganisms with a biopesticide capacity.

The yield of the melon plants in the soils uninfected by *Fusarium oxysporum* and amended by green composts were significantly higher than that obtained in the non-amended soil because of the increase in macronutrients, basically nitrogen, for which reason the soil with compost C (with its high nitrogen content) produced the greatest yield [11, 12, 13, 14]. Therefore, the use of green composts, besides improving crop yield, may also control the action of pathogens such as *Fusarium oxysporum* which frequently attack crops like melon.

![Figure 2: Incidence (%) of *Fusarium oxysporum* in melon plants regardless of soil and potential influence of the green composts on growth](image)

Whatever the case, in all the situations studied, the addition of compost is always considered a preventative step and if a pathogen does become installed more drastic measures will have to be taken. This fits well with its use in ecological agriculture, where all resources are used to the full, while chemicals should not be used. One research topic that is being investigated is how the biological effect against pathogens can be increased. One approach that is being carried out in our laboratories is to detect which are the biological agents contained in the compost, isolated them and reinoculated to higher dose to the compost before using them into soils. The preliminary results has demonstrated that the incidence of the pathogens on plant, reaching similar values to chemical pesticides. Thus means that the appropriate management of compost can be the reality to control plant disease in a near future in the ecological agriculture.
References


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