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The value of compost

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1. Introduction

Composting is the controlled decomposition of organic matter resulting in stabilized and sanitized organic matter that can be used as soil conditioner in agriculture. There exist multiple composting methods, varying from the small, home-made reactors used by individual households, to the relatively simple, on-site reactors used by farmers, to the large, simple to complex reactors used by professional composters to which the biowaste has to be transported.

If organic matter is targeted for agricultural use, the major reason for composting is sanitation (i.e. the inactivation of pathogens) of the material. In addition, apart from the presence of pathogens in fresh organic matter, returning great amounts of uncomposted, fresh organic matter to agricultural fields may have a stimulatory effect on plant pathogens already present in soil. The value of compost is difficult to summarize in one sentence, as its amendment to soil essentially has multiple positive effects, which in turn also affect each other. For example, an increase of soil organic matter content improves the water holding capacity, which makes plants less prone to conditions of dry weather. As a result of that, they may become more resistant against pathogens that specifically affect plants under stress.

This review aims to summarize the main ways in which compost affects the functioning of the soil. We focus mainly on composted biowaste, which we use in its broad sense, including organic household waste, green waste and crop residues, but many aspects also apply to composted manures.

2. Sanitation

A major goal of composting is the removal of pathogens. Although much emphasis is often put on the potential survival of some plant, human or animal pathogens during compositing, it must be realized that the majority of pathogens is promptly and completely killed during the heat phase of composting (e.g. Bollen et al. 1989). Moreover, many pathogens that are known to have some potential to survive normal composting conditions occur only rarely, which results in a very low chance of occurrence in biowaste. Tobacco Mosaic Virus is an example of such a pathogen. This virus can cause large crop losses when introduced into a crop, but it is virtually absent in Dutch agriculture. The common presence of this virus in tobacco of cigarettes smoked in the Netherlands (pers. comm. D. Peters, Virology, Wageningen University) is most likely of substantial greater risk for agriculture than its presence in compost. So, not only the fate of pathogens during composting needs to be included in a risk assessment, but also the probability of pathogen incidence in biowaste and the probability that presence in compost leads to phytosanitary problems.

The scale of composting is an issue that affects phytosanitary aspects: large composting facilities collect organic matter from a multitude of sources and one compost heap may therefore contain various pathogens. Moreover, such large facilities also distribute the compost to a large area. So, the need for inactivating the pathogens in such large facilities is therefore great, as otherwise there would be uncontrolled spread of pathogens. At the other extreme, on-farm composting facilities do not introduce pathogens from elsewhere, but reduced ability to control the composting process (relative to large composting facilities) may lead to limited survival of some plant pathogens. Although such a survival is unwanted, the consequences for farm management may be limited as these pathogens use to be all soil-borne, and their possible presence in compost is likely to be outnumbered by their presence in soil.

3. Effects of compost usage in agriculture and horticulture

3.1. *Organic matter content*

Soil organic matter is essential for maintaining soil quality by improving the biological, physical and chemical soil conditions. Soil organic matter consists of a variety of simple and complex carbon compounds and thus provides food for a variety of organisms. Soil organisms can affect plant growth directly by binding atmospheric N_2 by free or symbiotically living bacteria, by mobilisation of N, P and water by mycorrhizal fungi, through antagonism and predation of pathogens, by induction of resistance of plants against pathogens (Van Loon et al. 1998), and aspecific competition with pathogens. The mesofauna, notably the earthworms, contribute to the intense mixing of organic matter with the mineral fraction, which positively affects soil structure and water holding capacity. Organic matter increases the stability of aggregates thus reducing erosion, and decreases soil bulk density, improving drainage, aeration, root penetrability and soil porosity (Swift 2001). An increased soil porosity positively affects oxygen availability in soil thus reducing the incidence of anaerobiosis in soil and the associated production of greenhouse gases, and stimulating soil activity and root respiration. The effect of compost on soil erosion has been quantified in detail by Strauss and Murer (2001). Five years of compost addition to a loamy soil with an inclination of 8% resulted in 67% reduced soil erosion, 60% reduced water run-off, 8% higher bulk density and 21% higher organic matter content.

The reduction of soil organic matter content is of worldwide concern (e.g. Commission of the European Communities 2002; Loveland & Webb 2003). In the Netherlands, organic matter contents have been reported to be too low on approximately 30% of arable land by the Nutrient Management Institute (pers. comm. 2003). Losses of 240 and 760 kg C ha^{-1} yr^{-1} have been measured in Belgium (Vanongeval et al. 2000) and Austria (Janssens et al. 2003), respectively. This reduction has multiple causes, but increased mineralisation of organic matter due to intensive soil tillage and use of mineral fertilizers (leading to decreased application of organic matter in the form of animal manure, green manure, and organic soil improvers like compost) are among the most important. The build-up of the soil organic matter content resulting from repeated application of organic materials is explained by the characteristic properties of these materials, the dynamics of soil organic matter itself and the interactions between organic fractions applied and the receiving soil (e.g. Janssen 1984). Together, these factors determine whether soil organic matter contents will show a net increase or a net decrease.

If current agricultural practices are maintained, an increase in soil organic matter is obtained only by external organic amendments. Among these, compost belongs to the most stable sources of organic matter. Instead, animal manure consists primarily of easily decomposable organic matter, and its effect on soil organic matter content will be of a temporary nature only. An illustration regarding the importance of "stability" of the organic matter in crop residues, manures, and soil improvers and its effect on the accumulation of organic matter in soil is given in Figure 1. This figure shows the evolution of the soil organic matter content, which is initially 3%. Due to decomposition of residing organic matter, the total organic matter content decreases at first. Applying a stable source of organic matter such as compost will result in a net accumulation of organic matter on the long term. Applying, alternatively, a less stable source of organic matter like pig manure will result in ongoing decrease of the organic matter content in this soil. While results depend on soil properties, climate, etc., these trends are general. Note the time span involved in this kind of scenario calculations: build-up of soil organic matter contents is a matter of decades, not of years.

3.2. *Soil health and control of diseases*

An active and biodiverse soil microflora and fauna is generally considered advantageous for the suppression of plant pathogens. These organisms are heterotrophs and therefore depend for their carbon supply on organic matter. Without external supplies, carbon originates from autotrophic organisms, which are mainly green plants. It can be envisaged that in western intensive agriculture, carbon supply is rather

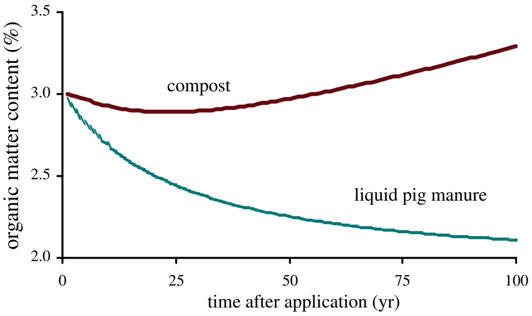

Figure 1. Development of soil organic matter content during one century resulting from annual applications of source separated composted biowaste or liquid pig manure. Application rates according to Dutch regulations (compost: maximum of 6 tons dry matter per hectare per year which equals about 42 kg P_2O_5, and liquid pig manure: maximum of 85 kg P_2O_5 per hectare per year).

monotonous, originating from only a few crops. For example, a typical rotation in Western Europe is cereals – potatoes – corn – sugar beet. Thus, carbon supply to the soil originates primarily from these plants. It is a tempting question whether such a monotonous supply leads to a narrowing in the diversity of the heterotrophic microflora and fauna and consequently, in the diversity of ecological functions of the soil. If this is the case, compost may contribute to a diversification of heterotrophic soil organisms.

A wide range of disease suppressive characteristics has been ascribed to compost amendments to soil (Hoitink & Boehm 1999) including root pathogens (primarily through competition and parasitism), but also shoot pathogens (through induced resistance). Suppression of soil-borne pathogens by composts is of interest because for many pathogens effective control measures are unavailable or existing measures will no longer be available due to their negative environmental impact as is the case for many chemical treatments. In this respect, the worldwide ban on the effective and widely used soil fumigant methyl bromide that is currently being implemented is important (Martin 2003). Typical to the disease suppressive effect of compost is its inhibition of a multitude of pathogens for a wide range of different types of compost. Probably, much of the disease suppression can be explained by aspecific competition for carbon sources. On top of that, the variety of substrate allows various different and more or less specific mechanisms to act. Hyperparasitic *Trichoderma* species often colonize compost spontaneously or are stimulated in soil after compost amendment (Bullock & Ristaino 2002) and act against various soil-borne pathogens. On the other hand, induced resistance is thought to have effects that are pathosystem-specific (Van Loon et al. 1998).

The effects of compost on diseases depend on a multitude of factors, the most important being the amount of compost applied, the disease pressure, and host characteristics. Effects of compost are notably large when peat is partially replaced by compost (Blok et al. 2002, Figure 2). This is due to the generally low disease suppressive characteristics of peat-based potting mix in combination with the relatively high compost application rate of 10–20%.

In arable soils in the European Union, the annual application rate is usually limited to approximately 10 ton dm/ha, which is equivalent to an application rate of approximately 0.35% (w/w). A persistent effect of compost application at such low application rates is to be expected only after applying compost for multiple years. Pathogen suppression effects in arable fields may be enhanced by concentrating the compost addition to planting or sowing holes. In this case, the focus will be on avoiding pathogens that attack young plants, such as *Pythium* and *Phytophthora* species. Pathogens that attack older plants may not be suppressed by this method, as when plants grow older the roots will grow into the compost-free soil, except in cases where compost incites induced resistance. Farmers may use higher amounts of compost if they have composted their own biowaste. Bullock and Ristaino (2002), for example, reported a decrease of disease incidence of *Sclerotium rolfsii* in tomatoes from 61 to 23% after application of 83 ton/ha of composted gin trash. This treatment had a strong positive effect on the microbial community including such well-known antagonists as fluorescent pseudomonads and *Trichoderma* species. So, one aim of selecting disease suppressive composts could be to select composts that selectively favour the native antagonists.

To enhance disease suppressive capability of compost, attempts are being undertaken to enrich compost with antagonists. If an antagonist can be added at the time the compost is most conducive to colonization by the antagonist, the compost can be used as a “solid state medium” for the antagonist. Detailed colonization studies have been performed

Figure 2. The effect of amending a peat-based potting medium with 20% (v/v) composted biowaste on the spread of the plant pathogenic fungus *Rhizoctonia solani* in rows of carrot plants. In the front-left control flat, with nonamended peat mix, the pathogen has reached the end of the plant row, killing all plants. In the front-right flat, with peat mix amended with a highly suppressive compost, the pathogen did attack only the first plants of the row. The other two flats, with peat mix amended with two other compost batches, show intermediate levels of suppressiveness.

only rarely and it may be questioned whether results from small scale experimental systems can be easily extrapolated to large compost heaps. Nevertheless, effects of antagonist amendment to mature composts have been reported by various groups (e.g. De Ceuster & Hoitink 1999; Cotxarrera 2002; Ryckeboer et al. 2002; Postma et al. 2003).

As for any disease management system, effects of a control measure depend on pathogen density and pathogen aggressiveness. On the one hand, compost should therefore not be regarded as a panacea to all plant pathological problems, but it may well be one of the essential measures that, in combination with other measures (such as wider crop rotation schemes and use of partial resistant crops), can replace methyl bromide soon.

4. Effects of compost usage on carbon sequestration and the greenhouse effect

Carbon sequestration is important to mitigate the greenhouse effect. By adapting agronomic management, CO_2 emissions from agricultural fields can be reduced. Examples of such adaptations are reduced tillage or no-tillage and grassland maintenance. However, these measures have only effect as long as they are permanently maintained (Dick et al. 1998). For example, the storage of C due to shallow ploughing is removed soon after deeper ploughing for one time (due to dilution and faster mineralisation). By adding compost to the soil, carbon is sequestered for a long time in the compost fraction that is resistant to decomposition. In addition, Spaccini et al. (2002) found that also more labile organic compounds, from e.g. fresh organic matter, can be protected by hydrophobic humic substances originating from compost. If the composting involves also a fermentation step, the energy carrier methane can be produced, which saves fossil fuel sources. Thus composting and compost application in agriculture contributes to reduction of the greenhouse effect. Alternative biowaste management options are less effective in this respect or have other drawbacks. Incineration of biowaste yields energy thus saving fossil energy sources. However, the process also costs energy and the net result is relatively low due to the high moisture content of most biowastes and the relatively low organic matter content. We estimate that application of composted household biowaste leads to a net reduction of 57 g CO_2 kg^{-1} biowaste while biowaste incineration results in a net reduction of only 25 g CO_2 kg^{-1}. Landfilling of biowaste results in significant methane emissions, which are harmful as methane is a strong greenhouse gas that contributes to breakdown of the ozone layer (Cicerone & Oremland 1988). Smith et al. (2001) and the Environmental Protection Agency of the United States (EPA 1998) conclude that separate collection of household biowaste followed by composting contributes least to greenhouse gas emissions.

In the potting mix industry, compost has been advocated as a substitute for peat (Hoitink & Kuter 1988), which is primarily due to the fact that peat is highly disease conducive, and partial replacement by compost renders it disease suppressive (Hoitink & Boehm 1999). In addition, a reduced need for peat will reduce the area of peatland reclaimed thus saving valuable nature area and reducing the amount of CO_2 that is emitted when peatland is reclaimed. Replacement of 1 m^3 of peat by compost reduces CO_2 emissions by 247 kg, which equals a decrease in loss of long-cyclic CO_2 of approximately 360 kg CO_2 per ton compost used to replace peat (Smith et al. 2001).

5. Conclusion

Composting of biowastes and compost application in agriculture has many positive effects. Most of these effects are hard to quantify and to express in monetary units. Therefore, these effects are often not accounted for in studies in which different waste management methods are compared. In many of these studies, mainly the energy yield of the various methods is evaluated resulting in a far from complete or balanced view. However, if all the benefits of compost, both the quantifiable and the hard to quantify ones, are taken into account it will be clear that compost is indispensable for the increase of the sustainability of agriculture and for the management of greenhouse gases.

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