Chapter 11
Interactions Between Beneficial and Harmful Microorganisms: From the Composting Process to Compost Application

Jacques G. Fuchs

Abstract Numerous microorganisms are involved in the composting process, but their precise roles are often unknown. Compost microorganisms are influenced by the composition of the substrate and by the temperature in the compost pile. In addition, different microorganisms also influence each other, e.g. through competition. In the first phase of composting, microbial activity increases drastically, leading to a rise in temperature. The initial bacterial dominance is replaced by a fungal one during compost maturation.

Compost management aims to achieve favourable conditions for beneficial and unfavourable conditions for harmful microorganisms. The type of input substrate, the size of compost piles, the frequency of turning, particle size, aeration and moistening all affect the microbial processes. They influence microorganisms mainly by affecting nutrient, oxygen and water supply. Sometimes, composts are inoculated with selected microorganisms. Harmful microorganisms are introduced into the compost mainly with the input substrate. They are mainly inactivated by high temperatures, but other mechanisms of inactivation have also been demonstrated, e.g. certain plant-derived compounds and antagonistic interactions. Beneficial microorganisms are capable of outcompeting harmful ones during the process and/or have a beneficial effect on crops after field application. Application of compost increases the microbial activity of soils, and crops are less sensitive to diseases after compost application (disease suppressiveness); the mechanisms are largely unknown. Better knowledge in this field would certainly allow optimizing the composting process to enhance disease suppressiveness.

J.G. Fuchs
Forschungsinstitut für biologischen Landbau (FiBL), Ackerstraße, CH-5070 Frick, Switzerland
e-mail: jacques.fuchs@fibl.org

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11.1 Introduction

Numerous microorganisms have been shown to be associated with composts (Ryckeboer et al. 2003b). It is evident that the microbial community, as a whole, plays an important role in the decomposition of organic materials and in the build-up of stabilized compounds. For most microbial species, however, the precise role in the composting process is unknown.

Among the microorganisms found in composts, there are not only beneficial and useful ones (i.e. microorganisms responsible for the regular composting process), but also those that are potentially harmful for humans, animals, plants or the environment. For example, plant pathogens are a normal component of crop residues, and if household waste is composted, human pathogens such as *Salmonella* are not uncommon. One of the most important goals of composting is the *inactivation* of these harmful microorganisms and the *development* of a beneficial microbial community. To achieve this, operators can adapt the compost management process in a way that is favourable for beneficial microorganisms and unfavourable for harmful microorganisms. This is described in a separate section below.

One of the challenging difficulties of studying microbial populations in compost is the interpretation of the results in relation to the methods used. For example, Dees and Ghiorse (2001) used three different methods to determine microbial populations (fluorescent direct counting, plate counts, and molecular methods), and their results differed 100-fold. A similar difference was observed by Atkinson et al. (1996). The difference may be explained by the fact that only active microorganisms can be counted, while also inactive microorganisms are detected with molecular methods. However, we do *not* know at present which of the methods gives the most adequate result in terms of compost microbiology.

11.2 Microorganisms at the Beginning of the Process

The microorganisms present at the beginning of the process are introduced with the original mixture of organic materials, with which the composting process is started. These microorganisms are all found in the natural environment. The most frequent in numbers are bacteria, and in particular actinobacteria, but fungi are also important members of the community. The composition of the input substrate influences the microbial communities (Klammer et al. 2008). This is particularly true for the populations found at the beginning of the composting process. Input substrates are often very heterogeneous and so are the initial microbial communities found on them. However, initial microbial communities of input substrates have rarely been investigated.

In source-separated household waste, only few mesophilic fungi but numerous thermophilic bacteria and fungi were found (Ryckeboer et al. 2003a). Food wastes containing vegetable residues have a low-initial pH, which favours the proliferation of fungi and yeasts and slows down bacterial growth (Choi and Park 1998; Ryckeboer et al. 2003b). On leaves, grass and brush compost samples at the first day of composting, Michel et al. (2002) found primarily Gram-negative, α-, β- and γ-proteobacteria.

Especially, the harmful organisms are substrate dependent. For example, animal manure and food wastes contain significant quantities of potential human and animal pathogens like *Escherichia coli*, *Listeria* sp. and *Salmonella* sp. (Grewal et al. 2007; Heinonen-Tanski et al. 2006; Hess et al. 2004; Jiang et al. 2004; Lemunier et al. 2005; Wichuk and McCartney 2007). Vegetable and crop residues may contain various plant pathogens (Bollen 1993; Hoitink et al. 1976).

Immediately after the start of the composting process, the microbial community changes drastically, and soon does not resemble the initial community any more as will be described in the next section.

11.3 Succession of Microorganisms During the Process

Immediately at the beginning of the composting process, the microbial biomass increases drastically (Hellmann et al. 1997; Narihiro et al. 2004). For example, Klamer and Baath (1998) observed a six-fold increase during the first day of composting shredded straw of *Miscanthus* with added pig slurry. Not all microorganisms multiply equally fast, and there are complex interactions between individual species. This results in significant changes of the microbial community (Klamer and Baath 1998).

The physical and chemical properties of the substrate change during the composting process. The microorganisms which are active first, degrade the original substrate, produce metabolites and create a new physico-chemical environment. This can then be used by other microorganisms (Ryckeboer et al. 2003a). Ishii and Takii (2003) postulate that the main factor affecting microbial communities in the composting process is the concentration and composition of dissolved organic materials. Quantitatively, the main components of organic matter are carbohydrates, proteins, lipids and lignin (Ryckeboer et al. 2003b). Different microorganisms produce different enzymes needed for degradation of the different substrates (Hu and van Bruggen 1997; Ryckeboer et al. 2003b; Tuomela et al. 2000).

Bacteria dominate the microbial community during the degradation phase (Beffa et al. 1996; Hu and van Bruggen 1997; Ryckeboer, et al. 2003a; van Heerden et al. 2002). During this phase, large quantities of dissolved organic carbon are usually available in the substrate. Depending on the input substrate (e.g. green waste, household waste), nitrogen may also be available in significant quantities. At a C/N ratio from 25 to 40, microbial activity is intense. This activity causes a rise in temperature, particularly in the centre of the compost pile. This phase is, therefore, also called "thermophilic phase." In general, the highest microbial numbers and enzymatic activities occur during this phase (Cunha-Queda et al. 2007). In composting of household biowaste, Narihiro et al. (2004) found that bacteria increased in two phases up to 10^{11} cells per gram dry weight, and then stayed stable during the process. Although the bacterial community was quantitatively stable, the authors observed a drastic *shift* from ubiquitous proteobacteria in the first phase to actinobacteria in the second phase. They attribute this community shift to antagonistic interactions between the different bacteria.

The increase of temperature that causes significant changes in the microbial communities (Hassen et al. 2001; Sundh and Rönn, 2002) is essential for the autosterilization of the compost (see Sect 11.4). Guo et al. (2007) found different microbial communities at different locations within the compost pile, which were related to the temperature at this precise location. Thambirajah et al. (1995) observed that during the peak heating phase, fungal activity was almost completely suppressed. Klamer and Baath (1998) observed that Gram-positive bacteria increased when compost heated up, and decreased against when the compost cooled down. Gram-negative bacteria and fungi increased with rising temperature up to approximately 50°C, but decreased at higher temperatures. After cooling to <50°C, these two groups increased again.

During the maturation phase, the number of bacteria decreases, but their diversity increases, as demonstrated by phospholipid-fatty acid profiling (Ryckeboer et al. 2003a). At the same time, the populations of fungi increase in quantity and in diversity (Ryckeboer et al. 2003a). Fungal activity is mainly important in the maturation phase of the composting process (Hu and van Bruggen 1997; Klamer and Baath 1998).

In summary, the microbial populations present in compost during different phases are the result of dynamic, complex interactions between the microorganisms and their environment. In the short term, high temperature is probably the major selective factor influencing the composition of microbial communities. High temperature is, itself, the result of high microbial activity, which depends on the substrate availability. However, the composition of the substrate is also greatly influenced by the metabolic activity of microorganisms.

11.4 Influence of Compost Management on Compost Microflora

The aim of compost management is to influence the microbial processes in a way that the input substrate is well decomposed, stable humus compounds are formed, harmful microorganisms are destroyed and beneficial microorganisms are promoted. All four aims must be achieved simultaneously, but this chapter is concerned only with the microorganisms.

Composting plants differ in the substrate which they use, as well as in the size of piles they make (composting system). They have several management tools at hand to influence oxygen level and moisture within the compost pile. Aggregate structure can be influenced by adapting the shredding of the input substrate. Further, oxygen levels can be influenced with forced aeration and/or by the frequency of turning the pile. If moisture is too low, the compost pile can be moistened artificially. The practical aspects of compost management are described elsewhere in Chap. 10 of this book (Klose et al. 2010). To some extent, the microbial interactions can be *influenced* by managing the environmental conditions. Oxygen and moisture are the two factors, which can be managed by the operator and have the greatest influence on microbial communities.

The oxygen level is known to be an important factor influencing compost quality. Enticknap et al. (2006) observed a growth stimulation of aerobic bacteria by oxygenation of a compost pile. Facultatively anaerobic microorganisms grow also in aerated composts (Atkinson et al. 1996). These authors postulate that anaerobic microorganisms in microenvironments within substrate particles may be responsible for a significant proportion of the metabolic activity in aerobic composts also in the later phases of the composting process. Thus, the size and structure of the substrate particles can greatly influence the activity of anaerobic bacteria. Watanabe et al. (2008) observed that populations of the family Bacillaceae clearly dominate under optimal composting conditions (98%), but that they were significantly decreased when the substrate was aggregated. Anaerobes or facultative anaerobes were dominant in the aggregates, but were *not* found in the non-aggregated substrate. The oxygen level in the composting material also has an indirect influence on the microflora, for example through the ammonia concentration in the substrate. If the aeration of the compost pile is poor, levels of ammonia increase, and the communities of ammonia-sensitive microorganisms decrease (de Guardia et al. 2008).

The moisture content in the composting material also greatly influences the microbial activity and the composition of the microbiota. Liang et al. (2003) observed that a minimal moisture content of 50% (w/w) is necessary for optimal aerobic microbial activity. However, too high a moisture content has a negative effect on the biological activity through the increased compaction of the material and the diminution of oxygen diffusion through the matrix (Das and Keener 1997). Not all microorganisms have similar needs in terms of water availability, and a change in moisture content can cause a shift in the composition of the microbial community (Takebayashi et al. 2007). In general, high water content favors bacteria over fungi (Finstein and Morris 1975).

The inoculation with selected microorganisms can also influence the biological processes and modify the microbial community. For example, Sasaki et al. (2006) added a commercial microbial additive composed of the genera *Alcaligenes*, *Bacillus*, *Clostridium*, *Enterococcus* and *Lactobacillus* to cattle manure compost. As a result, the temperature increased more quickly and the ammonia emission from the compost pile decreased more quickly. Also, the microbial composition of the manure changed and contained 10 to 100 times more mesophilic and thermophilic, aerobic bacteria, but a smaller number of thermophilic anaerobes. Inoculation is especially useful in unilateral raw mixtures, for example containing high amounts of woody material. However, the choice of the microorganisms is very important (Vargas-Garcia et al. 2005). They have to be competitive enough to colonize the material, and the quantity of inoculum must be sufficient. Otherwise, the competition of the native microorganisms does *not* allow the inoculum to develop in the compost.

The influence of inoculation on composting depends on the conditions of the process and on the characteristics of the raw material (Vargas-Garcia et al. 2007). The difficulty of inoculation is that each situation is very specific, and the inoculation strategy has to be adapted to each situation. Thus, it is not possible to give precise advice here. More research is clearly needed in this area. Our preliminary observations suggest that inoculation is not needed and has no effect if a balanced input substrate is used. In this context, a balanced substrate has a C/N ratio between 30:1 and 40:1, and a good structure allowing for adequate moisture and aeration.

11.5 Destruction of Harmful Microorganisms

With the initial substrates, microorganisms which are harmful for humans, animals or plants can be introduced into the compost (Wichuk and McCartney 2007; Noble and Roberts 2004). Noble and Roberts (2004) describe more than 60 plant pathogens, which potentially survive the composting process and which can be found in green wastes. Hence, the inactivation of harmful organisms is essential to obtain a safe compost.

High temperature is the most important factor for the "hygienization" (i.e. elimination of pathogens) of compost (Downer et al. 2008; Elorrieta et al. 2003; Suarez-Estrella et al. 2003). However, not all pathogens have the same sensitivity to high temperature (Bollen and Volker 1996; Wichuk and McCartney 2007). Effectivity of hygienization depends not only on the maximum temperature achieved within the compost pile, but also on the duration of the heat period (Bollen 1993; Elorrieta et al. 2003; Fayolle et al. 2006; Katan 2000; Suarez-Estrella et al. 2003). In addition, moisture also interacts with temperature in the hygienization process (Fayolle et al. 2006).

Contrary to common belief, high temperature is *not* the only mechanism for the hygienization. Even when the composting process does not reach the temperature level required for thermal kill, pathogens can be inactivated in compost. A number of compounds have been shown to be capable of pathogen inactivation.

Their occurrence varies with the substrate used. For example, Elorrieta et al. (2003) showed that the release of phenolic compounds during the composting process could be responsible for hygienization. Ammonia is generally present at relatively high concentrations at the beginning of the composting process. According to Gilpatrick (1969) and Lazarovits (2001), ammonia is well known to have some effect on different pathogens. Hoitink and Fahy (1986) showed that young composted hardwood bark contains ethyl esters of hydroxyl-oleic acids, which inhibit the development of the pathogen *Phytophthora* spp. Crucifers contain substances, which are toxic to some pathogens (Cohen et al. 2005; Koike and Subbarao 2000). Crucifers can be used for biofumigation, which can be considered as a specific mode of composting within the soil.

Antagonistic interactions may also lead to hygienization (Elorrieta et al. 2003). Different mechanisms can be involved. Competition for substrate has already been described above. Saprophytic microorganisms are often more competitive on dead substrates than pathogenic microorganisms. Some microorganisms produce volatile substances (Seewald et al. 2010), often secondary metabolites, which can be toxic for other microorganisms including pathogens (Wheatley 2002). For example, some isolates of *Trichoderma* spp. produce hydrolytic enzymes, which may destroy the cell wall components of many microorganisms (Krupke et al. 2003; Savoie et al. 2001; Williams et al. 2003). *Bacillus subtilis* can be an important inhabitant of composts (Ashraf et al. 2007; Kim et al. 2008; Phae et al. 1990; Yangui et al. 2008). This species is known for its production of antifungal substances, which are particularly active against plant pathogens.

It is generally assumed that the majority of the pathogens are destroyed during the composting process. An important question concerning the quality of the final product is to know whether pathogens from the environment are able to re-colonize the compost after the hygienization phase. Lemunier et al. (2005) tested the re-infestation risks of mature compost with *E. coli*, *Salmonella* serovar *enteridis* and *Listeria monocytogenes* by artificial inoculation. While *L. monocytogenes* was never detected in the different composts, *E. coli* and *S.* serovar *enteridis* survived between 3 and 90 days, but did not grow in the substrate. In sharp contrast, all three pathogens were able to proliferate after inoculation to a sterilized compost. This illustrates the importance of natural microbial populations in the compost for preventing re-colonization by pathogens. Jiang et al. (2002) observed a similar pattern: after artificial inoculation, *E. coli* declined more rapidly in manure-amended soil than in autoclaved soil. Cayuela et al. (2009) found that composts that were prepared with hoof or meat meal as a nitrogen source showed elevated abundance of *Acinetobacter calcoaceticus*, a bacterium that is suspected to trigger bovine spongioform encephalopathy (BSE).

In conclusion, good hygienization of composts *can* be achieved in most cases. Only very few pathogens, e.g. the tobacco mosaic virus (TMV) and *Xanthomonas malvacearum*, are critical in terms of their potential to survive a well-managed composting process (Bollen 1993).

11.6 Development of Beneficial Microflora During the Composting Process

As described above, a microbial succession occurs during the composting process, which is influenced by several factors (Ryckeboer et al. 2003a). In the case of good management practice, the population shift leads to a product containing mainly beneficial microorganisms, while the harmful microorganisms are eliminated during the process (see Sect.12.6, Minz et al. 2010).

In practice, crops growing on soil that had received compost are often less susceptible to diseases than plants growing on soil without compost (Arora et al. 2005; Boulter et al. 2000, 2002; Hoitink and Boehm 1999; Hoitink et al. 1997a; Suarez-Estrella et al. 2007). This phenomenon is known as "disease suppressiveness" (see also Sect. 12.7). Microorganisms are assumed to play an important role in disease suppression (Fuchs 2002; Hoitink et al. 1993; Noble and Coventry 2005; Tilston et al. 2002). There is evidence that beneficial microorganisms are more competitive in colonizing organic residues during the composting process than pathogens are. For example, Thornton (2004) observed that antagonistic *Trichoderma* species were able to outcompete the pathogenic fungus *Rhizoctonia solani* for nutrients, and thereby prevent its saprophytic growth. Cohen et al. (1998) could not attribute disease suppressiveness to the community of beneficial microorganisms alone.

Hygienization is not evenly effective throughout a compost pile. The outer zones of the compost pile do not reach temperatures high enough for hygienization. In these zones, mesophilic, heat-sensitive microorganisms including pathogens are present. During turning of a pile, the substrate from the outer zones is mixed with the hygienized material. Subsequently, the beneficial microorganisms grow faster than the pathogens. After a few cycles of turning and composting, the beneficial microorganisms outcompete the pathogens completely.

During the final process of compost maturation, the amount of the readily available nutrients is limited and the microbial community is stabilized. For example, the beneficial effect of green manure was more constant when it was composted than when it was not composted, independent of whether or not it contained pathogens (Bonanomi et al. 2007). Not all composts have the same ability to protect the plants against disease (Fuchs et al. 2008). Various authors observed that composts can show two different suppressive reactions: a broad, modest, suppressivity, or a specific suppressivity (Fuchs 2002; Fuchs et al. 2008; Hoitink et al. 1997b).

Addition of antagonistic microorganisms to compost is a promising technique to improve its suppressivity. Already in 1983, Nelson et al. (1983) increased the suppressive potential of compost by adding selected *Trichoderma* strains. They found that not only the addition of the antagonist is important, but also the strategy of inoculation of the antagonist, so that it can establish itself and develop its antagonistic activity. Chung and Hoitink (1990) also state that the inoculation of an antagonist must be optimized. Otherwise it cannot efficiently colonize the substrate, because the autochthonous microbial community inhibits it. Kwok et al. (1987) demonstrated that bacterial antagonists could establish themselves and protect specifically cucumber against *R. solani* better in sterilized bark compost media than in the medium with a broad suppressive effect.

11.7 Influence of Compost Amendments on the Soil Microflora

The interactions between microorganisms are not limited to the composting process alone. They continue also in the soil after the application of the compost. The microbiological activity of soils is increased by compost amendments. Angers et al. (1993) studied a soil, which was amended annually with 30 m^3 of compost of horse manure and wood shavings. In the second year of the experiment, they observed 50% more microbial biomass C and an ammonification rate increase by 30%. Crecchio et al. (2001) studied an amendment with 12 tons of municipal solid waste compost per hectare. This increased dehydrogenase activity by 20%. Fuchs et al. (2008) tested the effect of eight different composts and digestates on soil microbial activity. Six months after the amendment, the fluorescein diacetate (FDA) hydrolytic activity in the soil amended with compost or digestate was 20 to 40% higher than in the control, independent of the tested products. Other authors made similar observations (Nayak et al. 2007; Rumberger et al. 2004; Serra-Wittling et al. 1995; Tiquia et al. 2002). The overall quantity of microorganisms in the soil increases between 5 and 60% after addition of compost (Angers et al. 1993; Fliessbach et al. 2005; Ros et al. 2006a; Rumberger et al. 2004; Tabuchi et al. 2008; Tiquia et al. 2002; Zaman et al. 2004).

The diversity of the soil microbial community is also increased by compost amendments (Buckley et al. 2006; Dambreville et al. 2006; Drenovsky et al. 2004; Inbar et al. 2005; Kong et al. 2004). For unknown reasons, Cherif et al. (2008) did not observe a significant shift in bacterial community after the application of municipal solid waste compost. The influence of compost amendments on soil microorganisms depends on their quality. For example, the composting level (i.e. compost maturity) of cow manure had a significant effect on the microbial diversity (Kong et al. 2004). Compost application selectively influences the populations of soil microorganisms. For example, Roe and Ozores-Hampton (2003) observed that compost applications decreased the populations of aerobic and anaerobic bacteria in the soil, but increased the numbers of fungi, actinobacteria, pseudomonads and N-fixing bacteria.

The ways of compost influence on the soil microbial community are not fully understood. In many cases, it is not a simple multiplication of the microorganisms in the compost. In contrast, there is evidence that the addition of compost promotes the growth of indigenous soil microorganisms (Innerebner et al. 2006; Chu et al. 2007; Saison et al. 2006). However, the mechanisms of promotion are unknown in most cases. For example, Chu et al. (2007) conclude that compost promotes indigenous *Bacillus* sp. in the soil. Possibly, the supply of organic matter activates certain soil microorganisms (Buckley et al. 2006; Fliessbach et al. 2005). However, the quantity of organic matter applied with the compost is very small in comparison with the total organic matter present in the soil. This could explain why different types of composts had a similar effect on the bacterial community and activity in soil (Ros et al. 2006b; Fuchs et al. 2008). It would also explain the observation of Ros et al. (2006a) that the soil itself influences the microbiological activity and the community diversity more strongly than the compost treatments. Saison et al. (2006) report that compost affects the soil microbial community mainly through the physicochemical characteristics of the compost matrix. In conclusion, the establishment of microorganisms in the soil after compost application is still poorly understood, and more research is clearly needed in this area. A better knowledge of the mechanisms of establishment would allow to optimize compost application in practice.

Disease suppressiveness is obviously connected with the soil microbial community (Van Elsas et al. 2002). However, the respective roles of the native microflora in the soil and of the microflora added with the compost are not well understood, and the two are possibly working together. For example, Serra-Wittling et al. (1996) tested the influence of municipal waste compost on the suppressiveness of a loamy field soil against *Fusarium* wilt of flax. Compost addition did increase the suppressiveness of the soil, regardless of whether the compost was heat-treated or not, suggesting thereby that the microorganisms of the compost did not play a significant role in the soil. However, if the soil was heat-treated, non-treated compost could restore its suppressiveness. In conclusion, it seems that the microflora of the soil and the compost were both involved in the suppressiveness, and they mainly acted through nutrient and space competition with the pathogen. Such a complex interaction was also found by Inbar et al. (2005) for streptomycetes on cucumber roots.

Observations from practice support the role of microorganisms in disease suppressiveness (Bruns and Schüler 2000; Fuchs 2002; Hoitink and Boehm 1999; Reuveni et al. 2002; Tilston et al. 2002). In many cases, the suppressive effect disappears when the compost is sterilized (Chen and Nelson 2008; Craft and Nelson 1996; Malandraki et al. 2008). The majority of these experiments were performed with potted plants, where up to 50% of compost was added to the substrate. In the field, much smaller quantities of compost can be added. Therefore, findings obtained with potted plants cannot be extrapolated to field crops, and there are severe knowledge gaps concerning the effects of composts on field crops, including disease suppressiveness. Disease suppressiveness in the field is not always correlated with suppressiveness in the laboratory (Craft and Nelson 1996). In general, field conditions are much more variable than the conditions in the laboratory (e.g. meteorological conditions, indigenous microbial populations). For example, Santos et al. (2008) could demonstrate the role of compost microorganisms in the suppression of *Pythium aphanidermatum*. However, the in vitro inhibition of pathogens by isolated compost microorganisms did not correlate with the suppressive effect in the plant-soil-pathogen system. This indicates that mechanisms other than antagonistic relationships between compost and soil microorganisms could also be involved in compost-induced disease suppression.

11.8 Conclusions

There are complex interactions among different microorganisms, as well as among microorganisms, compost substrate and environment. In addition, these interactions vary in different phases of the composting process and after compost application to the soil. Although we know the outcome of the composting process, we are far from understanding all the interactions, mechanisms and processes leading to the end result. One of the more important factors in this relationship seems to be the competition for different organic substrates. As a result of microbial breakdown, the substrates change during the process, leading to a succession of microorganisms. Another important factor influencing the relationship between harmful and beneficial microorganisms is the temperature evolution during the composting process. Harmful microorganisms are more sensitive to heat than beneficial microorganisms, and the beneficial organisms seem to be more effective in re-colonizing the compost after the hot period. With appropriate management practices, the operator can affect some of the physical and chemical conditions within the compost pile, and thereby influence the balance between different microorganisms.

Compost application can have a positive influence on plant health (disease suppressiveness). To some extent, this can be attributed to beneficial microorganisms present in compost. More importantly, however, composts alter the microbial community of soils, or the two mechanisms interact.

With respect to practical application of composts, it is clear that compost quality, compost microorganisms, soil microorganisms and soil parameters are all involved in disease suppressiveness. However, the interactions and mechanisms are largely unknown. The processes need to be studied in depth not only in the short, but also in the long term. Research indicates that compost has a huge potential for disease suppression. In practice, however, this potential is not fully exploited. With a better understanding of these relationships, the practical use of compost for disease suppression could be optimized. In the long term, it can be imagined to produce specific "designer composts" for specific applications in specific soils, on specific crops and against specific diseases too. With such composts, high levels of disease suppressiveness are likely to be achieved.

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