LITERATURE REVIEW – SUMMARY

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Effects of Composts and Digestate on the Environment, Soil Fertility and Plant Health

Review of the Current Literature – Summary

Editors: Jacques G. Fuchs, Markus Bieri, Marc Chardonnens

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Jacques G. Fuchs, Markus Bieri, Marc Chardonnens (Eds.)

Effects of Composts and Digestate on the Environment, Soil Fertility and Plant Health. Review of the Current Literature

= English Summary (Chapter 8) of

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BUWAL Bundesamt für Umwelt, Wald und Landschaft
OFEFP Office fédéral de l'environnement, des forêts et du paysage
UFAFP Ufficio federale dell'ambiente, delle foreste e del paesaggio
SAEFL Swiss Agency for the Environment, Forests and Landscape

Table of Contents

1 Summary of the review of current literature

1.1 Legislation and international standards

In Switzerland, only the limit values for heavy metals and the details for delivery of compost and digestate are explicitly regulated (Ordinance on Substances). A distinction is made between *farm fertiliser* coming from facilities which house animals, whether treated or non-treated, and *recycling fertiliser,* whether vegetal, animal, microbial or mineral.

The compost, digestate and press water may be delivered to third parties only if the following limit values (in g/t MS) are not exceeded: *lead (Pb) 120, cadmium (Cd) 1, copper (Cu) 100, nickel (Ni) 30, mercury (Hg) 1, zinc (Zn) 400, polycyclic aromatic hydrocarbons (PAHs) 4, dioxins (PCDD) and furanes (PCDF) 0,20.*

In this respect Swiss limit values are amongst the most exacting in the European zone. They thereby guarantee that only the highest quality, separately collected biodegradable materials may be used. In contrast, the United States allows polluting levels that are about 20 times higher. In that country, the debate is centred on certain herbicides that are biodegradable only with difficulty (as for example Chlorpyralid and Picloram).

In Switzerland, nitrogenous fertiliser can be spread only during those times when plants can absorb nitrogen. Liquid fertiliser is authorized only when the soil is able to retain and store it. For recycling fertiliser, up to 25 t dry weight (DW) at most of compost or digestates per hectare or 100 m^3 of press water may be spread over the course of three years. In addition, the use of more than 100 t DW of compost and digestates during the course of a ten-year period is prohibited.

Hygiene requirements are currently under review. The minimum temperatures required during a particular period do not vary much from one European country to the next. In Switzerland, 3 weeks at over 55°C is mandatory, while the majority of countries require only 2 weeks.

The production of compost in Switzerland is financed principally by taxes upon receipt of the biowastes (gate fees). From the point of view of an optimization of benefits, this constitutes a presupposition unfavourable to the long-term promotion of quality. Nevertheless, the impulse for quality production must come from the producers themselves, if they don't want to run the risk that their products continue to be considered as waste.

In principle, legislation should regulate the fundamental aspects of all products, such as the limit values for heavy metals and pollutants, the criteria for sanitation and the quantity of foreign bodies. More specific requirements should be formulated in client- and use-oriented documents. Similar models are currently under discussion by the authorities in charge of legislation for the EU.

1.2 Influence of the application of compost in agriculture on the physical and chemical parameters of the soil

Tests of the effects of applying compost on the parameters of soil

The effects of applying compost in general, and in comparison with the effects of other organic fertilisers (farm fertiliser, sewage sludge etc.) have been the subject of various studies. The tests have often taken place in rather extreme conditions (heavy or light soil), with respectively short or intensive crop rotation (solely agricultural cultivation) or in relation to reconditioning soil (mining) or in intensive market gardening. Studies are lacking concerning the effects of compost in combination with farm fertiliser or intensive organic fertiliser (horn meal, castor bean cake, etc.). Likewise, there are only a few studies on the effects of applying compost during fairly extensive crop rotation or in mixed or fodder cultivation.

Properties and quality of the organic matter of compost

At the time of composting, the organic matter (waste from cuttings and biowaste collection bins, manure, paper waste, etc.) is degraded by aerobic micro-organisms into CO_2, H_2O and intermediary sub-products. These are used by other groups of micro-organisms for the synthesis of complex humic substances. As a consequence, there is a reduction of the C: N ratio from an initial level of 25 – 35 to around 17.

Quality of humus

The composition and properties of the organic compost matter differ from those of the soil in almost every parameter. Compost from green and kitchen waste shows values significantly higher than that of soil for parameters such as C_{org}, N_{tot}, pH, carbonates, cationic exchange capacity (CEC), salinity, chlorures and sulfates. It is therefore obvious that the application of stabilized organic substances will result in a modification of the composition of the organic matter of the soil and that this will depend on the quality of the compost and on the place where it is applied. The characteristic increase in the amount of lignin and of aromatic compounds is explained by the increased proportion of woody elements in the compost in relation to residues from crops and roots. Thus, the increased quantity of aromatic compounds after the application of compost cannot be automatically correlated to a more advanced humification. Generally, the site and the intrinsic qualities of the soil influence the humic characteristics of the organic fraction in a more durable way than fertilisation, and partially obscure the effects linked to the use of the soil.

Organic carbon and total nitrogen

In the majority of tests, the use of compost in agriculture or horticulture resulted in an increase in the amount of organic carbon (C_{org}) and total nitrogen (N_{tot}) in the superior horizon of the soil, until equilibrium is achieved after many decades. Generally, a close correlation was observed between the quantities of organic material brought by the compost and the increase of C_{org} in the soil. The level of equilibrium is essentially influenced by local factors (soil, climate), means of exploitation (tillage methods, crop-rotation), and the quality and quantity spread of the compost.

pH

The supply of compost generally leads to an increase or stabilization of the pH in cultivated soil. In function of its quality (level of carbonates), the use of compost can result in savings of non-negligible quantities of lime amendments.

Cation exchange capacity (CEC)

In general, the CEC of the decomposed organic material of soil is significantly higher than that of clayey minerals. Enrichment of soil with organic material can therefore contribute to a significant elevation of the CEC, above all in light soils with weak absorption capacity. Several studies demonstrated that, thanks to compost amendment, an increase in the level of organic material is as a rule linked to an elevation of the CEC in the upper horizons. In correlation with the elevation of pH and CEC, an increase in the base saturation percentage has equally been observed. No study is available concerning the effect of the application of compost on the absorption of anions.

Salinity, electric conductibility

In the course of a 3-year study of fertilisation in a sandy soil in northern Germany, with manure, kitchen waste compost or garden waste compost, the levels of salinity increased in the variant enriched with kitchen waste compost. In regions with a humid climate, this should not give rise to consequences, because of the relatively rapid leaching, however one should expect an increase in the salinity of soil in regions with an arid or semi-arid climate.

Redox potential

There is no study concerning the influence of the application of compost on the redox potential of the soil. More research is necessary.

Stability of the aggregates

The increase in the organic matter of the soil, the elevation of pH, the rise in calcium content and in the amount and activity the microbial biomass, are also accompanied by the formation of larger and more stable aggregates. The application of compost generally has positive effects on the stability of aggregates in the relatively short-term (< 3 years). This is maintained as well with continual applications. The use of “mature compost” improves the stability of aggregates significantly more than does “young compost”.

Density and porosity of the soil

Parallel to the growth in the stability of the aggregates was observed a diminution of the density of the soil. Nevertheless, this did not appear as quickly as the improvement of the stability of the aggregates. Thus, in studies extending over 3 years or more, only a tendency towards a diminution in the density of the soil could be demonstrated, whereas the effects on the stability of the aggregates was clearly apparent.

Water-holding capacity and water infiltration

The majority of studies have shown a significant increase in the capacity of soil to retain water after the application of compost. However this effect seems to appear only after a period of time. Whilst an increase in the water-holding capacity was observed in a site characterised by light soil, the application of compost on heavy soil led to a reduction in this capacity. It was also demonstrated that enrichment by compost resulted in increased infiltration of water in the soil. These clearly positive effects appeared above all in studies of long duration.

Resistance to erosion

In general terms a greater resistance to erosion was observed, and respectively a decrease in the tendency to erosion. The supply of compost improved resistance to both water and wind erosion.

Temperature results

Plots of land enriched with compost show a daily radiation balance of lesser amplitude. Fertilisation of leached brown soil with compost resulted in a higher underlying superficial temperature than that of the plot fertilised with mineral fertiliser.

Only the minimal temperatures of the soil of the plot fertilised with compost was slightly higher. These results are based on only one study. Further supplementary research is required.

Soil gasses

In studies conducted in southwest Switzerland, after 9 years of fertilisation with compost in 5 sites, an average increase in the aeration of the soil of 15 % was observed, compared with a non-treated control. The increase in soil respiration that is frequently observed is due to the modification of microbial activities and is not directly linked to the gas metabolism of the soil (gas exchange behaviour). More detailed research is necessary here.

1.3 The influence of the use of compost on the nutrition and growth of plants

Effects on yield

The field studies described in the literature concerning compost do not provide a very homogeneous picture. Details of the compost used are often lacking, for example the starting materials, the conduct of the fermentation, or the quality parameters. The quantity of mineral fertiliser added as a complement is often not precisely stated. The authors frequently declare themselves to be happy when, after the application of a quantity of normal fertiliser and a supplementary supply of compost, they don't observe a diminution of yield!

Manure compost

Studies described as having been carried out with manure compost in reality often involve a spreading of pure manure. In these cases, large quantities of manure have been spread, which over several years no doubt leads to an excessive enrichment of the soil with nutrients. Work on this theme often comes from American or Asian regions.

Effects of leaching of nutrients

A five-year lysimeter study characterised by the same level of N_{tot} noted that the intensity of leaching of nitrates decreased in the following order: NPK > manure compost > kitchen waste compost > sample > shredded wood compost.

Tests in pots

in barley cultivation, the leaching of N in pots fertilised with compost was lower than in the control, whilst in contrast the leaching of P was higher.

Simulations with the Danish model

the data in a 4.5 year study on the use of compost was used to simulate work over 50 years, with the aid of the Danish nitrogen dynamic simulation model (DAISY). Different applications of compost produced different results in sandy soil, but not in clayey soil. High returns and reduced levels of nitrates were obtained of winter wheat with 10 t of compost/ha and year, likewise with a nitrogen fertilisation corresponding to N_{min} of 20 kg N/ha.

Recommendations for taking into account the nitrogen of compost in fertilisation plans

The longer-term improvement of soil thanks to the effects of compost should be taken more into account in fertilisation plans to improve plots of land. In order not to increase the pool of organic nitrogen in the soil too much with the nitrogen from the compost, one can limit the quantities of compost applied to the soil. A good way of calculating this limit is by the farm's phosphorous budget, as is done in Switzerland, following the stipulations of the technical rules relating to environmental measures (which are required of farms entitled to financial benefits from the federal government).

The effects of compost on plant quality

In general, it has been noted that plants fertilised with compost contain fewer nitrates in their biomass. In contrast, accumulations of nitrates have also been observed in vegetables when the concentration of nitrates in the compost exceeds 5 % of the total N. Similarly, higher concentrations of vitamin C have been found in vegetables fertilised with compost.

The effect of maturity of compost (age) on the mineralisation of nutrients and on the yields qualities of plants

With a fertilisation by mature compost composed of 100 % garden waste, or by fresh composts composed of 70 or 100 % garden waste, the ray-grass showed a lower dry-weight yield than when fertilised with other types of compost. The net quantities assimilated were clearly inferior – for mature compost only for that constituted with 100 % garden waste. From the third cutting on, there was no longer any difference observed between fresh and mature composts. The total N assimilated attained a maximum of 7 % of the total quantity of nitrogen in the compost.

Incubation tests

During incubation tests, conducted with soil temperatures of 5° and 14°C during 552 days with composts of different maturity, no difference in mineralisation was observed, in contrast with their dynamics. For composts used as fertilisers, mineralisation is one of the most important criteria for quality. For composts used in larger quantities to improve the soil, or as potting soil, there are other organic products of degradation that affect the plants, such as short-chain fatty acids, which constitute important parameters of successful cultivation.

Effects of composts on the soil's characteristics

The ratio N_2:N_2O measured during denitrification correlates positively with the carbon/nitrate ratio in the soil water. The higher the ratio, the less N_2O is released under anaerobic conditions in the soil.

1.4 Influence of compost on soil organisms

Influence of compost on the microbial biomass

The effect of a supply of organic matter depends in part on the amount used, but very strongly on the quality of organic matter used. A good indicator is found by measuring the increase of available carbon in the soil, following the input of organic material, in relation to both its quantity and quality. Thus, it was noted that an increase of the hot-water soluble carbon in the soil corresponds to a linear rise of the nitrogen in the biomass. It could be demonstrated that aerobically stabilized sewage sludge compost more strongly and more durably encourages soil microorganisms than sludge stabilized under anaerobiosis, in relation to the quality of organic material. The effect of compost on soil seems therefore to be more long lasting compared to that of organic material stabilized anaerobically.

Influence of compost on microbial diversity

The supply of organic material to the soil will strongly influence the various microorganisms, and in different ways. This depends on the one hand on the dose, but also on the type of substance used. Thus compost stabilized aerobically will rather increase aerobic bacterial populations. This is true above all for cellulolytic microorganisms.

Analysis of phospholipid fatty acid profiles, which provide information on the diversity of the microflora, demonstrated clear differences between the soil of plots treated in a bioorganic manner, in comparison to that treated in a conventional manner. One interesting observation was that the profile of soil treated with organic fertilisers, small amounts of mineral fertiliser and a reduced supply of pesticides was found to lie between that of the two extreme treatment methods. On the basis of significant differences observed between the methods of treatment, one can conclude that the type of fertiliser exercises an important influence on the composition of the microbial community. Numerous studies show that the addition of available organic material to the soil increases the abundance of mono-unsaturated fatty acids, typical of aerobic bacteria, in fatty-acid profiles.

Influence of compost on microbial activity
Global parameters

It is not enough to know the quantity or diversity of the microorganisms in the soil to define their ecological importance. It is also essential to determine their activity. This can be done with the aid of the soil's respiration or of specific metabolic quotient (qCO_2). qCO_2 is a very sensitive parameter to perceive effects acting negatively on the microbial activity, as a higher qCO_2 indicates a less effective use of the organic substrates, which is often stress related. Several studies showed that the more easily degradable are the organic substrates, the more the metabolic quotient increases. It was only with the addition of biologically highly stabilized compost (with a high degree of maturity) that afterwards one immediately observed a decrease in qCO_2. The link between an increase in qCO_2 and stress factors could also be demonstrated in studies involving urban compost contaminated by cadmium.

In addition, a lower qCO_2 in soils treated with organic fertilisers shows that microbial communities are able to better use the organic material of the soil for their growth and require less maintenance energy.

Specific activities

Aside from the above-mentioned parameters, the activity of microorganisms in soil can be measured with the help of specific enzymes, which are generally involved in the metabolisms of carbon, nitrogen or phosphorus. The soil microorganisms contribute in an important way to make the nutrients of organic fertilisers available to plants and to reintroduce them into the life cycle. This is of the highest importance for organic agriculture, where only organic fertilisers can be used.

Studies of various enzyme activities show that compost applications principally increase activities specific to degradation, and that the effects of young compost are several times higher than that of older composts. In particular the dehydrogenase activity, which serves as an indicator for redox microbial systems, can be considered as a measure of the intensity of the microbial metabolisms in the soil.

On several occasions a net gradation of the enzymatic parameters of the soil appeared only in long-term studies. The β–glucosidase activity, an indicator of the degradation of carbon bonds, showed a graded increase under the effects of annual supplies of compost.

Since most phosphorus is organically bound in the majority of soils, phosphatases have a particular importance for plant nutrition. Composts can stimulate phosphatases, whether directly, by an increase in the supply of organic matter, or indirectly, by increasing the availability of water. The metabolism of phosphorus by the microbial biomass is in general more rapid in soils treated organically with compost.

Influence of compost on the degradation of toxic organic compounds

The degradation of xenobiotic substances is improved by compost. The addition of organic material to a soil often improves the rate of degradation of pesticides and polycyclic aromatic hydrocarbons, in function of the type and reactivity of the organic material and its effect on microorganisms.

Effect of compost on arthropodes

Several studies have shown that the number of collembola is closely correlated to the increase in total carbon caused by the supply of compost. Here one observes a marked shift in diversity in favour of hemiedaphic and epigeic collembola, which live near the surface. However, the effects are in general less pronounced in the case of mites.

Effect of compost on earthworms (Lumbricidae)

Given the central role in soil formation played by earthworms (Lumbricidae) within the soil macrofauna, compost application must be seen as particularly positive from this point of view. In effect, the number of earthworms depends strongly on tillage and humus management, and can therefore be notably increased by a supply of compost.

Thus one finds both the greatest number and largest biomass of earthworms in fields of wheat fertilised with compost, followed by plots fertilised with an organic-mineral variant. The same results were observed in an eight-year comparative study of vegetable and apple cultures, farmed in a biodynamic or conventional manner. In studies of fertilisation with worm compost, it was found that different kinds of earthworms were not stimulated in the same way. Here too, the supply of compost caused a shift in species diversity.

Effect of compost on nematods

The antagonistic effect of compost on populations of nematods was demonstrated on many occasions. This result could be due to several factors: either to nematicid substances and to toxins produced as the organic material in the soil was degraded, or to an improvement in the tolerance of the hosts to the parasitic nematods, or again to a change in the soil's microbial population and its activity, in particular if the supply of compost has introduced or stimulated nematophagous microorganisms.

It is also interesting to note that in numerous studies, non-parasitic nematods were stimulated by the supply of compost. One can deduce that compost encourages predator nematods and parasitic fungi, which specifically destroy the eggs of certain parasitic nematods. This could be exploited in the fight against these parasites.

The inhibiting effect of compost on nematods could also be due to chemical factors: during in-vitro studies phenols, in addition to ammonium, aldehydes and fatty acids, were shown to have strongly nematicide properties. Organic acids in compost seem to have similar effects.

Aside from the many publications that demonstrate the inhibiting action of compost on the development of parasitic nematodes, thus illustrating an important positive effect of their use, there are also some works showing compost or other organic substances to have a feeble, non-existent or even stimulating effect on nematodes.

1.5 Influence of the use of compost on plant health

The interactions between composts and plant health are varied and complex. They include the inactivation of pathogens during fermentation, acting on the interactions between plants and their pathogens with the help of composts, as well as the production and use of infusions of compost and of compost extracts in protecting plants against leaf diseases.

Natural sanitation during the composting process

Almost all pathogens, whether they are fungi, bacteria or viruses, are killed during the composting process. The sanitation process takes place during the first phase of composting. During the subsequent maturation phase, on the other hand, pathogens are no longer killed. The most important parameter to insure the sanitation of organic material is the temperature, provided that there is sufficient humidity in the mass during fermentation.

Compost and soil-borne pathogens

There are also numerous examples of composts that are able to protect different types of plants against certain parasites. These effects are not limited to simple observations in a laboratory; they can also be demonstrated in practice. By choosing good composts, these effects can also be repeated in a targeted fashion. When using composts to combat plant diseases other aspects, related to the fertility of the soil, should also be taken into account. In effect, it is possible that other factors, such for example as an excess of compost, can have a negative impact.

Another important point to take into account is that not all composts have the ability to efficiently inhibit plant diseases. The strong variability in the observed effects amongst different samples is certainly the greatest obstacle to the large-scale use of composts with the specific aim of protecting plants. The production of composts with defined, constant qualities is an indispensable requirement for satisfying the expectations of those using compost in this way.

Means of action

The protection mechanisms by which a compost acts can vary depending on the targeted organism. Thus, while the inhibition of *Rhizoctonia* seems to be the result of microorganisms, there are probably mycostatic substances resistant to heat which act against *Fusarium sp*. Nevertheless the principle protection mechanism against plant diseases seems clearly to depend on the microbial activity of the compost. Numerous studies show that heat treatment, which kills the microbial flora of the compost, also reduces the suppressive effects to zero. Treating a mature bark compost for six days at 60° is sufficient to destroy its potential to fight diseases.

The suppressive effect of compost and its microbial activities is in addition often correlated to the rate of hydrolysis of fluroesceine acetate. The following organisms were regularly isolated from composts with suppressive effects: *Trichoderma asperellum*, which acts against fusarium wilt of tomatoes; *Acromonium* sp., isolated from solid waste compost and which parasites *Phyfophthora nicotianae*; *Bacillus subfilis*, which survives the hot phase of degradation; *Aspergillus* sp., *Geotrichum* sp. and non-sporulating *Pythium*. Various efficient antagonists were isolated from bark composts, for example: *Trichoderma* sp. *Gliocladium* sp., *Penicillium* sp., *Mortierella* sp., *Paecilomyces* sp., *Geomyces* sp., *Ophiosfoma* sp.

In certain cases composts can also act directly against pathogens, that is the composts compromise their survival in the absence of the host plant, preventing the development of a pathogen population . In other cases, the compost only acts on the pathogens in the presence of the host.

Physical and chemical parameters

Aside from biological activities, certain chemical properties of composts can also contribute to their suppressive potential. A decline in the concentration of carbon is correlated to an increase in suppressive potential. Substrates with increased suppressivity are recognizable by their low nutrient availability and by their substantial population of highly active mesophytic microorganisms.

Aside from the microbial activity of the compost, the amount of nitrates in the soil seems also to have a certain influence: an elevated level of nitrates can also reduce the suppressive activity.

There are also examples which show that above all it is the global supply of nutrients and the improved physical properties of the soil that operate in a beneficial way on plant health, resulting in a reduction in the damage due to fungal pests.

Stimulation of the microbial activity of the soil

Compost probably acts as much as a result of its intrinsic microbial activity as by its stimulation of microbial activities in the soil. Applications of compost in a soil increase the existing suppressive effect against *Fusarium oxysporum* f.sp. *lini* on flax. This effect is proportional to the quantity of compost administered. Autoclaved compost exercises the same effect in a non-treated soil, but not in an autoclaved soil.

The difference between compost and other organic fertilisers

The principle difference between composts and other organic fertilisers resides in the particular composition of the composts' microbial populations. Thus, it could be shown that applications of rice straw supplied energy and nutrients to the pathogens as much as to the telluric saprophytes. The respiration levels were much lower after applications of mature straw compost in a soil than after applications of straw. The risk of encouraging pathogens was significantly less with applications of compost than with straw. Similar results were obtained with fresh and composted bark. This is probably due to the additional cellulose that fresh organic material provides and which parasites can use for their growth. In compost, there is considerably less available cellulose.

The importance of the composition of input materials

Various authors have studied the importance of input materials in the suppressive effect of composts. The general impression which emerges from the work analysed is that the composition of the initial mixture plays only an indirect role. The degree of physiological maturity of the composts, the differences in microbial populations, as well as the availability of nitrogen seem to exercise the greatest influence. Some authors were able to use these factors in order to explain the differences in efficiency with which composts combat plant diseases. Only the addition of materials containing lignin during the maturation phase, as for example hemp fibres as a substitute for peat, resulted in a significant increase in the suppressive potential of the composts, probably through stimulation of the *Trichoderma* spp. population.

Quantities administered

The suppressive effect of composts is in general proportional to the quantity administered. Since compost is well buffered microbially, it is nevertheless possible that in the case of too high levels of application an inhibition of plant growth is rather observed, because of a too high salinity, or because of an excess of nutrients, acting contrary to the suppressive effect.

Degree of maturity of the compost

There is a distinction between "general" and "specific" suppressive effect, that is between "quantitative" and "qualitative" effect. The source of these different types of effect is to be found in the microbial populations which colonise the compost and which evolve during the entire degradation process. Compost of different ages can therefore have different effects on the pathogens.

Numerous authors were able to demonstrate that a determining role is played by the degree of degradation of the organic material. Very young composts in general show a very weak suppressive effect. Too high a level of nutrients and energy (glucose, aminoacids, etc.) in the fresh organic materials can inhibit the synthesis of essential enzymes in the antagonistic organisms.

The more the maturation advances, the more the suppressive effect increases. Once maturity has exceeded a certain threshold, when the organic material has reached a high level of stability, the microbial activity decreases and the compost loses its suppressive effect.

In certain cases, young composts are more efficient than mature composts. Thus, it was possible to successfully protect cabbage plants from attack from *Plasmodiophora brassicae* with the help of different young composts. The protective effect decreases with the increase in the degree of maturity of the compost. For certain pathogens, the influence of the degree of maturity is not known.

Measures resulting in an increase in the suppressive potential of compost

Various authors promote the idea of a targeted inoculation of compost with chosen antagonists, which would guarantee a stable quality. An inoculation with *Trichoderma harzianum* effectively increases the suppressive effect of composts after the hot phase.

Other possibilities are offered by composting techniques at several phases. Thus the proportion of chitinous derivatives with suppressive power could be considerably increased in the compost, thanks to crab wastes.

The addition of materials rich in lignin during the maturation phase stimulated lignin-degrading fungi, such as *Trichoderma* spp.

Long term effects / practical application

There exists today a sufficient number of well-documented works which confirm that the positive effects of composts on plant health are not solely laboratory phenomena. Thus, thanks to the application of garden waste compost on raspberry cultivation (20 l per linear metre in spring and autumn), it was possible to efficiently combat red core disease (*Phytophthora fragariae* var. *rubi*).

The effect in the field is nevertheless not always as specific as in the case of raspberries, but generally the growth and health of plants are improved. Thus in one study, the quantity of marketable potatoes could be significantly increased through the application of spent mushroom compost.

The positive effect of composts in open fields probably results from several factors: the nitrogenous fertilising of the plants, the stimulation of the microbial activity of the soil, or the activity of the microorganisms of the compost itself.

In practice, composts could offer an alternative to methyl bromide treatments. But for this method to be effective, particular attention should be paid to the quality of the composts. The important parameters are the nitrogen budget, the maturity and stability of the composts, as well as the time of application. In Switzerland, compost is successfully applied after steam sterilization of the soil, in order to provide life to the soil, to increase the efficiency of the treatment and to ensure that the effects are long lasting.

Compost and induced resistance

Composts don't only improve the health of plants against soil-borne pathogens. During studies on roots, where only half were treated with compost, a resistance to *Pythium ultimum* in cucumber plants was induced. These effects were lost by the sterilization of the compost.

Not only composts, but also their extracts can induce a resistance in plants. In these cases, the induction mechanisms are then heat resistant.

Different compost extracts and applications of compost in the soil protected barley plants from attack from *Erysiphe graminis* f.sp. *hordei*. An additional effect was observed when these two methods were combined.

The resistance induced by the compost seemed to be based more on a reinforcement of the plants' defence reactions against infections than on an activation of antagonistic organisms.

Extracts of compost and leaf diseases

As has already been mentioned, aqueous extracts from compost can be vaporised directly onto the leaves like regular fungicides, in order to protect the plants from diseases. Numerous works cite such effects. An introduction to the current literature concerning these techniques has just been published.

Choice of composts

The question of the best composts for the fabrication of extracts has not yet been clarified in detail; there are still some contradictions. On the basis of one study, it seems that extracts from grape marc compost are more efficient than those from compost made from sheep manure or from a mixture of chicken and sheep manure. In effect, the latter loses its ability to protect sweet peppers against *Botrytis* sp. when the extracts are diluted 5 or 25 times, while this is not the case for extracts made from grape marc compost.

Aside from the composition of the initial materials, the degree of maturity of the compost also plays a role in the efficiency of the extract. Composts stored for a long time, which are physiologically stabilised, show themselves to be less efficient than younger composts. *Influence of the duration of the extraction*

The duration of the extraction process influences the efficiency of the extract. With spent mushroom compost for example, the efficiency of the extract increases with the duration of the extraction and reaches its maximum after 5 – 9 days. The minimum duration of the extraction necessary to protect vine plants against *Botrytis cinerea* is at least 10 days.

Other authors have found that the inhibition of the germination of spores and the mycelial growth of *Botrytis cinerea* was independent of the duration of the extraction. The *in vivo* effect of the extract was strongest for an extraction duration of 3 to 8 days.

A reduction of the protective effect in extracts with a long duration of extraction was also observed. The study concerned the suppressive effect of compost extracts on grass root rot caused by *Pythium graminicola.* The maximal suppressive effect from the disease was attained with a period of extraction of four days. After fourteen days the suppressive effect was lost. It was also found that the temperature of the water used for the extraction influences the results: below 20°C, the effect of the extract decreases.

Sensitivity of the extract to heat

Most reports mention that heat treatment causes a loss of suppressive effect in composts. Numerous authors have observed that, on the contrary, the activity of compost extracts is also conserved after a heat treatment, even after the solution has been filtered through a 0.2 µm. membrane. Moreover, it seems that the active principle of spent mushroom compost resides in small non-protein heat-stable molecules which are produced by anaerobic microorganisms.

The situation in this regard is not clear. There are also observations where the compost extracts have lost their efficiency after sterilisation. The authors have therefore deduced from them that the protection mechanism is of a microbial nature.

The contradictory data indicates that there are probably different active principles in the compost extracts that are responsible for protecting plants against diseases. It is probable that some secondary metabolites excreted by the microorganisms during the extraction are responsible for the protection of plants. Depending on the physiological stage in which the extract is used, this process could be disrupted by the death of microorganisms. Further research is necessary to shed light on these questions.

Microbial effects of the extracts

The effects of the compost extracts on the microbial equilibrium of the phyllosphere have been frequently described. The clear correlations between the microbial activities in the phyllosphere and the suppression of disease have also been demonstrated. The protective effect comes from the inhibition of the germination of the spores, from antagonisms and competition with the pathogens, as well as from the induction of resistance reactions in the host plants.

The fact that the sterilisation of certain compost extracts does not result in a reduction in efficiency speaks in favour of the nutrient input hypothesis.

Influences on pathogens

In some experiments, a direct inhibition of the parasitic fungi by the manure compost extracts could be observed. It is for this reason that induced resistance is the most likely protection mechanism in higher plants. Nevertheless, numerous other authors have recorded an inhibition of sporangium formation, of conidia germination, and also of mycelial growth in several fungi (*Plasmopara viticola*, *Venturia inaequalis*, *Botrytis cinerea*, *Cochiobolus carborum*, as well as *Sphaeropsis sapinae*).

Results of field tests

In certain controlled conditions, apple trees could be efficiently protected from apple scab (*Venturia inaequalis*) with the help of compost extracts. In field tests, this protection was found to be insufficient, probably because of the very high disease pressure, due to the humid atmospheric conditions which prevailed. During other trials, a weekly treatment of the apple trees significantly reduced the scab on the leaves, however not on the fruit.

Successful field applications of compost on grape vines have been described. A good control of Brenner disease (*Pseudopeziza tracheiphila*), as well as of downy and powdery mildew (*Plasmopara viticola* et *Uncinula necator*) was obtained after five treatments of compost extract. An efficient protection of potatoes against *Phytophthora infestans* was otained in a field test, especially when compost extracts were enriched with antagonistic microorganisms.

There is also an article by the same author concerning a successful use against *Botrytis cinerea* in strawberry cultures.

Successful applications of compost extracts are also known in vegetable crops. A weekly application of sheep manure compost extract on tomatoes resulted not only in a reduction of *Alternaria solani*, but also in an increase in the crop yield. A significant reduction in damage due to *Botrytis* and to powdery mildew (pathogen: *Leveillula taurica*) in tomatoes was obtained in greenhouse market cultivation with sheep manure compost extracts. With the same weekly treatment frequency applied to lettuce, it was not possible to reduce the incidence of *Botrytis*, however the intensity of the disease was nevertheless reduced. This permitted the sale of a significantly larger number of lettuces.

Field tests of the seed disinfection of wheat with powdered skim milk, wheat flour and algae powder thus strongly reduced common wheat bunt (*Tilletia caries*). The use of compost extract as an adhesive increased the efficiency of the preparations tested.

Increase in efficiency

The addition of nutrients in the extracts didn’t improve their efficiency. On the other hand, the addition of 0.5 % casein improved the efficiency of the compost extracts, even though when alone it shows no inhibiting action on diseases. The same results were obtained with pine needle oil (0.05 %).

Spreading compost on the soil and treating barley leaves with extracts of compost largely protect the plant against *Erysiphe graminis* f.sp. *hordei*. A combination of the two methods has an observed additional effect.

1.6 Conclusions

Composts can lastingly improve the soil’s properties. Various studies have shown that with time, applications of composts increase the stability of the aggregates and the porosity of the soils which have received them. Both qualities concern characteristics of the soil which increased its value from the point of view of cultivation. The soils whose aggregates are more stable disintegrate less easily and benefit from an increased gas exchange, as well as better rainwater percolation in the upper horizons. An increased porosity improves the gas exchange in the deeper horizons, facilitating a percolation of water from the surface to the deeper layers of the soil.

Generically, composts can be considered to improve the soil. Although the importance of the recycling of nutrients in composting should not be underestimated, composts must in no way be directly compared with mineral fertiliser. Rapid results can be expected only in the case of particular composts, characterised by a high proportion of nitrates of bacterial origin. The majority of compost is recognised by its relatively high level of lignin (when there is a large proportion of wood in the input materials). If the fermentation works well, these substances contribute in an important way to raising the level of humus in the soil. With the exception of peat soils, one generally looks to obtain a higher and therefore more “stable” level of humus. This results as much in a notable increase in the soil's capacity to store nutrients as in their availability for plants. This effect is all the more accentuated in tropical soils. Well-managed humus can prevent aluminium toxification. In such soils, it is possible to obtain a great deal by means of a careful management of the compost. From this point of view, it is essential that the user is able to correctly evaluate the value of the compost directly at the time of its production. Therefore one can’t avoid the establishment of reliable, simple parameters which permit to predict the effects of the compost on the soil and on cultivated plants.

Nor is it surprising that the application of organic material also stimulates the fauna and flora of the soil. Many studies indicate that the use of compost globally stimulates earthworms. The importance of these for agriculture has already been discussed in detail elsewhere.

As for the suppressive effects on plant diseases and phytophageous nematodes often observed when compost is used, they open up entirely new perspectives. The organisms living in compost which can inhibit soil-borne fungal diseases and phytophageous nematodes are also known in part. Nevertheless the conditions under which they can develop in compost are only gradually beginning to be understood. As a result composting, respectively an appropriate control of the fermentation process, consists above all in piloting the fermentative organisms. In order to make progress in this area, it is going to be necessary to look more carefully into the microbial process during composting. In this area as well, compost retains the potential to significantly increase its value, which could provide it with a very pre-eminent place in sustainable agriculture

This study of the literature has shown the gaps in present-day knowledge, as well as the unanswered questions to which a response must be found in the interest of the composting industry. These questions concern amongst others the dynamics of plants nutrients, the mechanisms responsible for protection against plant diseases and phytophageous nematodes, the combined use with farm waste fertilisers and other organic fertilisers, the combination of applications of compost with other methods of plant cultivation and production, and the effects of digestate and digestate compost. In all of these areas, there is a notable need for research.

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