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Literature Study

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Contents

SUMMARY AND CONCLUSIONS

The study summarises the literature and the current knowledge on the effect of compost fertilisation on the soil plant system.

After surveying the principle significance of quantity and quality of soil organic matter (SOM) for the maintenance of functions, health and fertility of soil (chapter 2) specific experimental work and studies are examined. This is done by systematically evaluating beneficial effects on relevant soil parameter and plant performance (chapter 3). Every chapter is structured in 3 sections:

1. Introduction on the functional importance of the specified parameter (e.g. SOM, crop yield, plant nutrition, physical soil properties etc.)
2. Exemplary demonstration and summary of characteristic results from literature
3. table of literature examined with short description of experimental design and key results

The most important contributions and conclusions drawn from the 2001 Symposium „Applying Compost – Benefits and Needs“ (Amlinger et al., 2003c) a summarised.

Since the recycling of *organic waste compost* as soil amendment precaution is demanded in order to prevent any substantial decrease of soil quality two chapters on potential adverse effects caused by spreading pollutants were added (chapter 3.7 ‚Heavy metals', chapter 3.8

Finally chapter 4 gives a survey on legislations and technical standards and guidelines on EU level as well as for federal and provincial provisions in Austria.

A comprehensive knowledge of short to long term effects of continuous soil management (i.e. compost application) is the pre-requisite for optimising land use measures in order strengthen the soil ecosystem.

This expertise must provide the necessary orientation for legislative framework or environmental subsidies programmes respectively.

The nitrogen fertilisation effect of compost use has been excluded from this work since this was covered by a separate study of 2003 (Amlinger et al., 2003a; http://www.umweltnet.at/article/archive/6954)

Key results of beneficial effects

Organic matter (OM) status und reproduction (chapter 3.1)

All long term application trials result in increased SOM concentrations. Important conditions are: quantity, type and maturation of composts applied and soil properties (above all particle size distribution) respectively. The majority of trials show highest SOM effects with composted material. Only few experiments could not differentiate between the C sources (straw, manure, compost). However, well matured compost leads to a higher SOM increase than *fresh compost*. The stable C fraction responsible for OM reproduction is highest in mature compost (50% of total compost C).

The mean SOM increase in compost amended plots amounts between 0.1 – 1.9 % whereas control plots show a SOM decline. In average the SOM demand of agricultural soils is balanced by applying 7 und 10 Mg ha^{-1} d.m. compost every year. Yet, plant residues not withdrawn from the field must be taken into account.

Pot and laboratory trials indicate mid term C mineralisation ratios of 1 to 20 % of the total C_{org} applied. This supports the hypothesis that compost serves as a carbon sink and contributes to the mitigation of greenhouse gases (chapter 3.2).

On the other hand long term fertilisation trials demonstrate a rather low variation in decomposable C_{org} e.g. 0,2 to 0,6% in manure fertilised plots. The results are well correlated with the clay content. Clay soils show twice the humification rates of sandy soils. However, composition and stability of SOM pools are still unsatisfactorily explored.

The main challenge to optimise compost fertilisation system under different cropping systems and site conditions is to assess the specific impacts and interactions between plant nutrition and long term soil improving effects.

The impact on SOM, the efficiency in OM reproduction by means of composition of source materials for composting and compost process is another matter of needed research. Among others this would require innovative analytical methods for a better characterisation of the compost OM (humus stability, OM reproduction factor, mineralisation potential under typical site conditions)

Effect on Yield and economic assessment (chapter 3.2)

Most of the investigations give appositive yield effect and productivity as compared to unfertilised and in longer lasting experiments also mineral fertilised control plots. Predominantly because of the low N availability in compost combined fertilisation schemes often show good results.

Another consistent result is the fact that compost fertilised systems balance yearly climatic variations, leading to a more stable productivity over the years.

Economic assessments of compost fertilisation show – especially in vegetable cropping systems – a compensation of higher management (spreading) costs by more stable yields of marketable products.

All results very much depend on the site specific biomass production potential and the crop rotation. Crops with longer growth period show better responses than those with short ones.

Key factors influencing the crop production are:

- quantity and frequency of compost application
- crop rotation
- site specific yield potential
- supplementary mineral N fertilisation

Many experiments indicate that at common application rates (ca. 7 to 10 Mg d.m. y^{-1}) the yield effect occurs only after 3 to 6 years. In other words, field trials below 3 years cannot be recommended since they would not allow any interpretation on the mid term crop response to the fertilisation system. However, in the first years when compost is used, compost applications every 2 to 3 years at higher rates lead to better effects than low rate yearly applications.

Some investigations, e.g. with vegetables, do not show significant yield effects but give evidence on improved quality parameters of harvested fruits (oil of pumpkin seeds, potatoes, grass). Most vegetable show a positive response on compost use.

Plant nutrition (chapter 3.4)

Long term compost management lead to a constant increase of total and available stock of macro nutrients (P, K, Mg) and calcium in the soil.

The nutrition efficiency of total compost inputs ranges between 30 - 50 % and 40 - 60 % for phosphorus and potassium respectively.

Thus over a 3 years crop rotation a total compost rate 30 Mg TM ha^{-1} balances the P und K demand and ensures the basic fertilisation. The lime supply ranges between 600 und 1600 Kg and corresponds to a preservation liming measure.

In summary, compost can be defined as a organic multi nutrient fertiliser. Besides its soil improving ability (humus reproduction, liming effect), macronutrients such as phosphorus, potassium and magnesium can be fully accounted for plant nutrition during a crop rotation.

As a consequence compost substitutes mineral or synthetic nutrient sources in agriculture. The substitution potential for Germany is estimated with 8 to 10 %, similar values can be assessed for Austria. Estimating approximately 100 mill. Mg organic waste recycling on EU level 500.000 Mg N, 300.000 Mg P_2O_5 and 600.000 Mg K_2O could be replaced by the use of compost.

Sulphur in compost has a similar low availability of 5 to 10 % in the year of application. In the long run the S mineralisation would improve and the demand for additional sulphur fertilisation in former S deficiency soils would be reduced.

As far a the supply with trace elements is concerned the experimental results can be summarised as follows:

- The elements loads do not effectuate measurable increase of concentrations in the soil
- Though an increased plant uptake for Cu, Mn and Zn is reported
- In any case compost is a multi nutrient source for soils with a micro nutrient deficiency

The experiments, supported by the contributions to the Symposium show that it would be inadequate to judge compost mainly for its short term fertilisation effect due to the applied plant nutrients. Compost

Compost supplies nutrients in the several binding forms to the soil matrix. It has an dynamic impact on exchange processes between root system and sorption complex. This is mainly caused by the humified OM and the colloid properties of the humic substances. In this context the importance of amino acids and amino sugars for the formation of humic substances and aggregation should not be neglected. This again is the basis for an improved water regime and transformation processes.

This justifies the establishment of a comprehensive and long term concept in evaluating compost in contrast to mineral nutrition driven fertilisation.

Enhancing buffer properties, cation exchange capacity (CEC), pH value (chapter 3.5)

An important benefits of compost fertilisation is the liming effect by adding calcium mainly in form of calcium carbonate. This ensures a preservation liming measure at moderate application rates of up to 10 Mg d.m. ha^{-1}.

Acidification processes can be balanced by maintaining or enhancing soil pH through regular compost use. Only very few experiments have lead to a pH decrease after compost application.

The expected increase of CEC is confirmed by the examined literature.

Enhancing soil physical properties (chapter 3.6)

The most important soil physical indicators are aggregate stability and distribution; hydraulic conductivity, infiltration, resilience against erosion, water retention capacity, pore volume and distribution.

All these parameter are strongly related to quality and quantity of SOM

Further, there is a well documented interaction between microbial activity which has an significant impact on aggregation via intermediate catabolic products.

In general terms it can be concluded, that the increase of the particulate SOM stock by applying organic materials and compost will promote soil structure prominently in clay and sandy soils. Positive effects can be expected by well humified (promoting micro-aggregates), as well as fresh, low-molecular substances (promoting macro-aggregates).

Aggregate stability is the best and most frequently investigated parameter is positively influenced through compost additions. Due to the slow transformation of organic components inducing the stability of small particles, which can hardly be influenced by cultivation measures, changes are often observed only for micro and macro aggregates > 20 µm.

In correspondence to this predominantly pore volume >50 µm is increased most prominently in loamy soils. Erosion trials with stratified irrigation systems showed a clear correlation between increased SOM, reduction of soil density and soil loss as well as runoff of surface water.

There is still a lot to learn about the interdependency between the different organic matter pools, their specific properties and physical parameters. A better understanding would be necessary in which way compost quality could be defined in order to achieve a more focussed soil improvement under different soil conditions.

It became evident that soil quality – i.e. structure related properties – cannot be described with only one single parameter. Only in combination, a set of parameters may give a robust interpretation on the improving effect on soil quality and soil functions!

In the Symposium it was indicated that the addition of specific mineral components (stone dust, clay minerals) the formation potential of stable aggregates during composting can be increased.

The experimental results on the impact of compost fertilisation systems on soil physical properties can be summarised as follows:

- Reduction of soil density on the majority of investigations
- Increase of aggregate stability
- Increase of pore volume and hydraulic conductivity
- Increase of the proportion of macro pores, predominantly at higher compost rates
- Together with improvement of soil structure infiltration is increased
- Reduction of erosion processes due to higher stability of aggregates and improved infiltration
- No consistent increase of field capacity
- Results depend mainly on soil properties, compost maturation and application rate
- Soil temperature:
    - Increase of soil temperature due to darker colour of soil
    - Reduced variation of soil temperature at high compost application rates
    - Compost mulching systems: reduced warming up in spring and cooling effect in summer.

Heavy metals (chapter 3.7)

Organic mater and substances in compost (predominantly the complex polymer humic acids) are absorbed by the soil matrix. Thus compost input to soils alters the sorption and exchange dynamic for minerals and thus for potential toxic elements.

The additional sorption surface areas supplied with compost are only effective if they are not occupied with metals already. This demands the production of quality assured composts made from 'clean' source materials with low metal contamination.

The rotting process, above all the state of maturation and humification is decisive for mobility of heavy metals. This mainly affects the formation of organo-mineral complexes. In general terms it has been shown that with proceeding maturation the proportion of dissolvable OM declines together with the soluble heavy metal fraction.

The derivation of limit values for pollutants in compost ensuring a long term compost application in a n environmentally sound way needs a careful balancing of the identified benefits with potentially negative effects on the soil-plant system. This concept follows the principles: (i) application following *good agricultural practice* (GAP) optimising the benefits to soil functions (e.g. humus reproduction, general soil improvement, nutrient supply); (ii) respecting that scientifically approved soil threshold values for the multifunctional use of soils are not exceeded in a long term scenario. As an orientation we used the precautionary threshold values for sand/silt/clay soils of the German Soil Protection Ordinance. Only when those values are exceeded additional load limitation would apply.

Primary prerequisite is the exclusive use of clean source separated raw materials in order to guarantee the lowest possible pollutant input over time. Based on thousands of compost data, this would fulfil the goal of precautionary soil conservation.

By respecting these principles of precaution (application rate according to GAP, consequent separate collection and quality assurance) a mid term slow increase of heavy metals in the soil can be tolerated. There is no science based or environmental reason to establish limits for compost at a level which would exclude a considerable percentage of composts from the use (e.g. at the level of soil background concentration).

In any case binding limits must consider coefficients of variation which are compost of a number of components (seasonal and local variations, sampling errors, inhomogeneity of sampled lot, analytical variances between laboratories etc.)

After evaluation of existing studies and investigations it can be concluded that the 90^{th} percentile of ten thousands of composts plus 50% tolerance would fulfil the above mentioned criteria of technical viability (recycling security) and precaution (long term environmental protection).

Pesticides and organic pollutants (OPs) (chapter 3.8)

The study does not describe potential concentrations of organic compounds but the sorption and decay potential during composting and compost applied soils.

Due to the high level of humified OM composts contribute to sorption and immobilisation of OPs, thus reducing adverse effects to other environmental compartments and consumers. Further, based on increased biological activity the conditions for the oxidative biological decomposition of pollutants are improved. Both mechanisms are supported by the examined literature.

Also during composting, the microbial decomposition processes which require optimised conditions (oxygen availability, humidity, temperature, C/N, pH etc.) is an important aspect of quality improvement.

Abiotic (photolysis, hydrolysis) and biotic transformation processes take place in parallel, but the latter are considered to be the most important.

Better maturation and humification promote organic sorption processes. Also mineralisation is described as more effective in compost soil mixtures when well matured compost was used. So called 'fresh compost' results in a less effective mineralisation rate. This was specifically found for PAH and other hydrocarbons.

For *PCBs* decay rates during composting range up to 45 %. On the other hand a concentration process can be found similar to the mineral fraction. Biologically degradation and volatilisation affect mainly congeners with a low chlorination level.

Also *PCDD/F* show a trend to concentrate during composting. The formation of dioxins and furans during the process can only be observed at temperatures > 70°C and if preceding compounds are present (such as *Trichlorophenol* und *Pentachlorophenol*). Also here biologically degradation affect only congeners with a low chlorination level.

AOX and Pesticides show a better decay during composting than in soils. Highest degradation takes place during thermopile stages Background concentration in composts is well below existing guide an limit values.

LAS, NPE, DEHP: those compounds, mainly found in sewage sludge, are efficiently degraded under oxidative conditions.

Accumulation scenarios of persistent pollutants (PAK, PCB, PCDD/PCDF) show, that, respecting realistic half life times in soil, continuous compost use will not lead to an increase of soil concentration. Also in a worst case scenario for PAH the accumulation would be moderate and precautionary soil threshold would not be reached by far. The natural decay in soil generally over compensates the additional input by compost and atmospheric deposition.

However there is always the science based derivation of soil threshold levels which guarantee a safe food production and ground water maintenance and which must be observed against potential soil changes in time.

The results can be summarised as follows::

- In principle the use of clean source materials from separate collection systems do not result in critical concentrations of pesticides or other known organic pollutants investigated in literature.
- The composting process as such based on temperature effects as well as oxidative microbial and biochemical processes contributes in many cases to en effective decay of micro pollutants.
- Scenarios of inputs of persistent organic pollutants (PCB, PAH, PCDD/PCDF) with regular compost applications demonstrate – even under worst case conditions – no critical accumulation in soil.
- Specifically the use of well matured compost increases PAH and pesticede degradation as well as stabilisation (fixation) in soil.

Soil biology (chapter 3.9)

Soil fauna and flora plays a key role for the ‚functioning’ of the soil eco system. However the level of transformation and other biotic processes depends mainly on the existence and availability of sufficient organic matter (organic carbon) sources. If a minimum of crop residues and dead microbial biomass is not available exogenous organic matter must be added in order to maintain the necessary for microbial soil functions

There are three essential impacts of compost application to soil with respect to biotic transformation capacities:

- Optimisation of the habitat soil (e.g. water and air household, increase of the specific surface where accessible water is adsorbed)
- Supply of food, providing the trophic level for soil biota; this is the basis for successful development of a diverse microbial community and enzymatic activity
- Introducing compost biota into soil as an inoculant.

Two fraction of organic matter are responsible for the level of microbial activity: easily available organic substances may increase the short term transformation rate and biodiversity significantly. This is only a temporary effect. A more long term persisting increase of microbial biomass is only possible if the stable OM pool in soil is constantly increased by continuous compost or other EOM addition. This maintains the necessary food source as well the physical conditions of the microbial habitat.

Summary of experimental results: impact of compost use on biological activity in soils:

- general increase of biological activity
- increase of microbial biomass
- increase of dehydrogenase activity
- in most cases increase of protease activity
- in most cases increase of urease
- Substrate induced respiration (SIR) and β-Glucosidase: increase with stepwise enhanced compost rates
- Respiration: significantly enhanced
- Mesofauna: higher numbers of species und
- Increase of earth worm abundance

Suppression of plant deseases (antiphytopathogenic potential) (chapter 3.10)

The phenomenon of suppression of mainly soil born plant diseases by compost addition to soils and growing media has been known since the 1960ies. Since then systematic research is carried out.

The main mechanisms of biological control of plant disease are:

- competition,
- antibiosis und
- hyper parasitism.

Further it is distinguished between a "generic" and a "specific" suppressive ability. The latter means relates to biological control effects on definite diseases.

Today it is evident that stability (maturity) of the compost is of essential significance. Only poorly matured compost may promote the growth of pathogens, whereas mature compost suppresses their propagation.

Well stabilised organic material supports the activity of biological control mechanisms by microorganisms. Further important conditions are: timing of compost application before cropping, salt content, mobilisation of nutrients.

But the phyto-sanitary impact of compost is not limited to suppressive or lethal effects on pathogens. Though the most prominent results were obtained with substrates under controlled in green house conditions, plant health promoting effects are also reported from field experiments. Here the mechanisms are not so specific, rather a more balanced nutrition and crop development strengthens the resilience against plant diseases.

It seems that physiologic maturity, microbial community and diversity, as well as nitrogen availability pay a more important role than the type of input material used for composting.

The poorer the microbial community the less is the probability of an effective disease suppression might be. Consequently the suppressive effect is directly proportional to the amount of compost added.

Here the conclusions are taken from Bruns (2003) presented at the Symposium „Applying compost– benefits and needs“:

- Suppressive effects of bio- and yard waste composts produced in model or in commercial systems on *P. ultimum* could be demonstrated in standard bioassays and in practical horticulture.
- For large-scale utilisation of disease suppressive composts the production process has to be defined and a quality assessment scheme has to be developed in order to produce composts with consistent properties.
- Procedures to assess the curing state of composts and predict the interactions of plants, pathogens and beneficial micro organisms need to be developed.
- Studies on suppressive effects of compost in soils are promising. Research to increase the utilisation of suppressive composts in soils should be intensified. If this is successful composts originating from source separation could have an improved market potential.

Assessment of regulatory framework conditions in Austria (chapter 4) with respect to the literature results

The existing regulations and guidelines for compost use provide little flexibility specifically for short term humus build-up in depleted soils. This is also valid if further soil conserving measures are considered (inter cropping, reduced tillage, green manure etc.).

The Austrian compost Ordinance introduced a maximum average application rate in agriculture of 8 Mg d.m. compost ha^{-1} in the turn of a 5 years period. This figure has been adopted also by some of the provincial sludge and compost regulations.

Though 80 % of the compost nitrogen is utilised for the formation and maintenance of humic substances the total N-content is accounted with the N-limitations of the Austrian Water Act and its implementation orders of the EU Nitrate Directive. Therefore compost is handled like any other far more mobile N source. This problem has been tackled comprehensively by Amlinger et al. (2003a, 2003b).

In conclusion it can be said that an application regime of up to 10 Mg TM ha^{-1} within a period of 5 years, distributed in 2 applications at minimum, would give the desired humus and soil improving effect still without endangering the soil eco system.

However, the principle of *good agricultural practice* must always be respected by considering site and land use specific conditions, observing nutrient and SOM status over time.

Final remark

The literature provides robust and widespread evidence, that compost fertilisation contributes to multiple benefits to the soil plant system improving and stabilising soil functions and properties as there are: long term productivity including plant health, soil biodiversity and transformation capacity, soil physical properties with all positive side effects of water and air household and contributes to a better performance in sequestering carbon in soil.

1 THE QUESTION BEHIND

1.1 Introduction

Composting is one of the recycling methods for organic substances (R4) described in Annex 4 of the Waste Framework Directive (EC) n° 442/1975. Further more R10 is *'land treatment resulting in benefit to agriculture or ecological improvement'*.

The assessment to what extent compost meets this recycling objective and under which conditions is the task of the study.

The ecological benefit is indeed one of the key requirements for the acknowledgement of recycling of organic waste also in many national regulations. In addition to demand that a secondary waste derived material should be of equivalent quality and fit for use as a primary product. In the case of compost it is frequently compared with commercial (organic) fertilisers and the nutrition effect.

The main difference between a fertiliser and a soil amendment is the level of plant available nutrients. Key parameter identifying an *'Organic Fertiliser'* according to the Austrian Fertiliser Ordinance is, besides a minimum content of organic matter of 20% d.m. also minimum concentration for plant nutrients (N_{tot} 0.6%, $P_2O_{5\,tot}$ 0.3%, K_2O_{tot} 0,5% d.m.).

The designation *'Full Fertiliser'* requires at least 1% d.m. of N_{tot}, $P_2O_{5\,tot}$ und K_2O_{tot}.

In the case of compost this strict demarcation between soil amendment (or soil improver) and fertiliser is inadequate. On the one hand compost supplies plant nutrients of different levels of availability. In the case of phosphorous, Potassium or magnesium compost serves as a short term fertiliser. On the other hand it is a classic organic soil amendment which fulfils its soil improving benefits predominantly by long term repeated application over many years. In addition, due to the wide range of source materials used composts represent a very wide variation of nutrient levels.

Already this gives evidence that compost must be classified as multifunctional soil amendment which reveals its specific effects on the soil-plat system in a dynamic manner depending on the application regime, soil properties and cropping systems. A simplifying assessment, manly reduced to nutritional effects would be inadequate.

In practice, farmers ask for the beneficial effects of compost. Therefore the proper application system merely depends on a clear definition and knowledge of the beneficial effects in its manifold aspects.

Once the benefits are defined, the perception or appreciation by farmers depend also of other factors. Since biowaste or green waste composts are derived from waste, in the past it was difficult to achieve an adequate price for compost when offered to farmers. Rather a "recycling fee" was offered or compost was given for free in order to motivate farmers to accept the "black box" compost.

This of course can only be overcome if – based on quality assured products and the acknowledgement of the long term benefits – farmers can be convinced of the credibility of the product compost

Due to the low nutrition effect (especially in the case of Nitrogen) experts often question the definition of compost as organic *fertiliser*. Furthermore it is claimed that potential pollutants must be evaluated in relation to nutrient supply (e.g. the Cd/P_2O_5 ratio). This of course leads to a significant disadvantageous perception of compost against other fertilisers which contain higher concentrations of nutrients.

A further problem is the unequal availability of the macro nutrients. If the application rate would in theory be derived from the available N percentage of 5 - 10% in order to cover the demand of the entire vegetation period, this would result in most cases to a far to high phosphorous or potassium inputs. This has to be seen on the background of sometimes critical high level of background concentration in many continental, middle European soils.

The second perception of a philosophy of soil management has its origin in the organic farming movement, which defines fertilisation rather as soil nutrition or stimulation of soil biology as a measure to maintain or improve soil fertility..

This goal is the key motivation for the use of compost.

Besides the nutrient supply two main aspects of soil improvement are considered

- Organic matter (OM) or Humus supply (or *Humus reproduction* by providing a high proportion of stable humic substances)
- Liming effect (by providing components [CaCO3] with alkaline effects)

The following figure summarises the beneficial effects associated with regular compost application

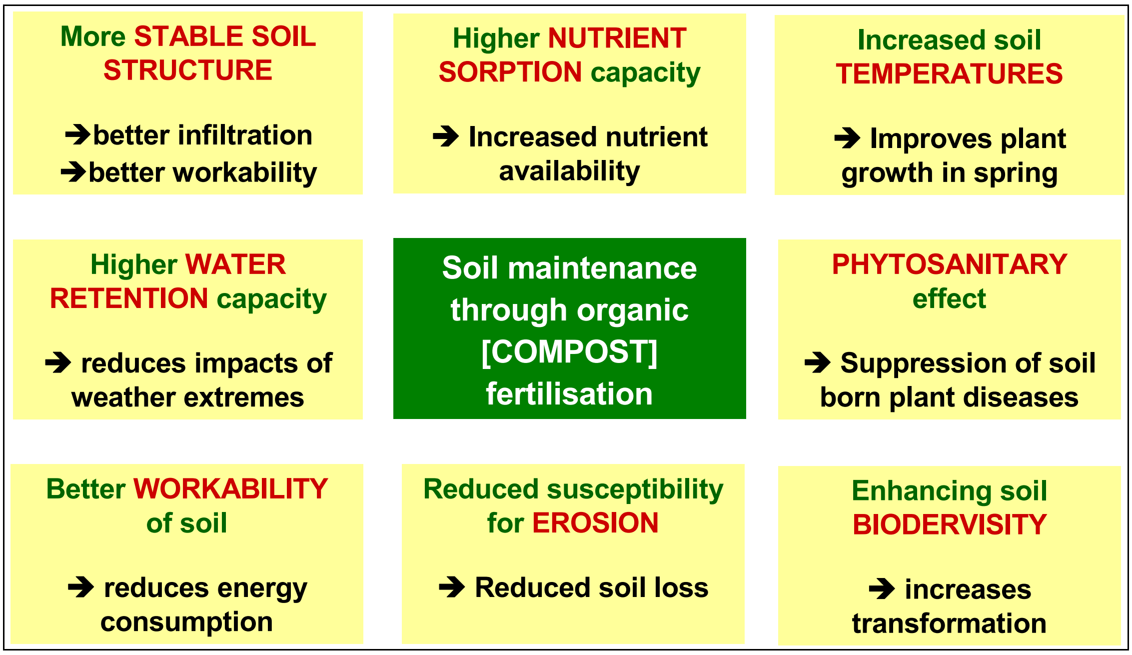


FIGURE 1-1: THE MANIFOLD BENEFICIAL ECCECTS OF COMPOST FERTILISATION TO TO THE SOIL – PLANT ECOSYSTEM (BGK, 2005)

Since the changes in soil properties and soil fertility indicators will not occur after one or two subsequent compost uses, it needs long term trials and experience to achieve well documented and justified results. However it can be argued that too strict restrictions for nutrient loads would limit admissible compost applications at such a low level at which the envisaged long term soil improvement (humus maintenance and enrichment) could not be achieved.

Of course there is also the question how far the change of soil parameter may be interpreted as indicator of a measurable direct effect of compost amendments in fulfilling the generic criteria

- sustainability
- soil protection
- savings of resources und
- enhancement of soil fertility

In this context we may distinguish between direct effects (soil organic matter) and indirect impacts (e.g. water content at field capacity, increase of aggregate stability) as indicators for the desired ecological benefits (e.g. higher infiltration and thus diminishing erosion).

Consequently, the central task of the literature study was to view and evaluate the effects of compost application systems on the improvement of soil and soil fertility based on:

- general pedological knowledge and soil science and
- results from field and laboratory experiments

and to compile the answers and conclusions presented in literature.

In this study the entire question of the effect of compost use on the ***nitrogen dynamic*** in soil, (organic binding, risk being drained off with percolation water, uptake and usability by crops) is not covered. This was drawn up extensively in the a survey[1] by Amlinger et al. 2003a[FA1] (see also Amlinger et al., 2003b).

1.2 Soil improvement – Soil fertility

In general terms, improvement means enhancing components of the qualitative status or of functional processes of the productive soil horizon. In order to assess any improvement it is necessary to define and quantify parameters which describe soil quality. This leads to the questions: how is soil quality determined.

1.2.1 Soil fertility – the central function of soil in agriculture

A first attempt would describe functional objectives and target values, i.e. it is necessary to define requirements in relation to functions, which the soil should satisfy as landscape compartment and in fulfilment of a defined utilisation.

It is obvious that there will not be a universal soil quality and function parameter.

The common term *soil fertility* occupies agronomists and soil science since agricultural soil use became a subject of scientific perception. There might be two aspects to be considered when searching for a general definition of *soil fertility* and thus reflect the farmers key expectations:

1. It means the level of *productivity*, i.e. the output per unit of area and time period (e.g. vegetation period)
2. It includes the constancy or stability of the production level that is sustained over more than one production periods (e.g. several vegetation periods, one or more crop rotations, generation(s))

Further the term fertility implies, that soil is a part of a living entity which interacts with its adjacent environment following not only physico-chemical but the rules of biological processes

[1] *„Kenntnisstand zur Frage des Stickstoffaustrags in Kompost-Düngungssystemen“ [State of knowledge of nitrogen leaching from compost amended soils]* ZL. 34 2500/48-III/4/99; http://www.umweltnet.at/article/archive/6954; not available in English.

(metabolic transformation, respiration, growth, formation and degradation of organic substances)

Quantifying crop yield (biomass productivity) over a number of years could be one approach to define a site specific soil fertility. But fertilisation and other crop and soil management impacts might distort an objective assessment. As an extreme example, high yields can also be achieved without soil (hydroponics). Thus yield is an important criterion but as such not always meaningful.

The output per unit of area is a sub-function of soil (soil as a habitat). The assessment of the sustainability of this function might serve as a parameter describing soil fertility. If certain management measures (e.g. soil conservation methods) aim for as enhancing this function, productivity can be addressed as an relevant indicator.

Soil parameters as such may serve as indicators for soil fertility if those parameters – in combination – sufficiently describe the level to which the desired soil functions are obtained.

However, besides the production aspect, today a science and environment orientated soil management must include further ecological criteria (functions) in order to describe soil as functional element of the landscape – and these directly and indirectly have a major impact on the wider definition of soil fertility):

- filter-, buffer- and transformation function
- the function of soil as biological habitat und gene reserve (preservation of *biodiversity*).

This functional perspective is strongly linked to the perception of the precaution principle in soil protection. The inclusion of "long term productivity" as one aspect of the natural soil functions implies the thorough consideration of eventual adverse side-effects caused by any fertility orientated soil management.

Consequently, the conservation and maintenance of the function "*buffer, material balance*" (e.g. in avoiding to over-stress the buffer capacity for nitrogen with the goal to prevent nitrate leaching into the ground water) is equally respected as the postulation of productivity

A single-edge intensive land management aiming at the one and only parameter *output per unit of area* (e.g. high life stock units, high nutrient balances, mono cultures) would have an undesirably competitive impact on the ecological functions

Depletion of filter, buffer and transformation functions for mineral and organic substances caused by intensive SOM degrading management methods will under certain site conditions result in negative impacts of ground water quality and quantity. Thus all measures which are targeted on the maintenance of all the mentioned soil functions have a far reaching ecological significance.

This perspective attributes a new dimension to the traditional definition of *soil fertility.*

The above made considerations imply two further aspects of *soil quality*:

- the *resilience against erosion* (soil loss through wind and water)
- the long-lasting *maintenance of a site specific and land use adapted organic matter level* combating the tendency of on-going or complete mineralisation or desertification (the latter depends mainly on climatic conditions and land management and is a major threat in sub-tropic to tropic climates, semi-arid and arid regions)

Quantity and quality of SOM is tightly linked with soil physical properties (aggregation, pore volume and pore size distribution) and surface structures. The formation of these structural properties may influence the water household of entire landscapes and regions dramatically.

In addition to the need of a balanced spatial landscape and soil utilisation (Sealing; structural depletion of agricultural land) the physical degradation of agricultural soils which in some cases cover large land areas contributes significantly to flooding events of the recent years.

The key parameter involved is the specific surface area of soil aggregates with its ability of water retention and as infiltration medium.

However, this study will concentrate on Middle European climate and soil conditions.

2 BEHAVIOUR AND CHANGE OF SOIL ORGANIC MATTER IN DEPENDANCE OF CLIMATE, SOIL AND SOIL MANAGEMENT

2.1 Soil and Soil Organic Matter (SOM)

Soil organic matter in this study is defined as the entire solid organic soil matter including humic substances and dead plant tissue. This definition does not distinguish between inert or labile, active, soluble or insoluble, pure organic or organo-mineral compounds, humic or fulvic acids, hydrophilic or hydrophobic, aliphatic or aromatic substances.

Topsoil is generally considered to consist of four broad components: -

1. Mineral Matter   2. Organic Matter   3. Air   4. Water

The relative proportions of these vary, but on a volumetric basis it is likely that the proportions in cultivated, medium textured topsoil would be of the order: 45% mineral matter; 5% organic matter and 50% pore space. The pore space will be occupied by air and water depending upon the moisture status of the soil. This organic fraction will consist of living plant and animal material, dead plant and animal material where the origin of the material is clearly discernible, and well decomposed organic material called Soil Organic Matter (SOM).

This SOM fraction will broadly consist of:

1.) partially decayed plant residues (no longer recognisable as plant material)

2.) microorganisms and microflora involved in decomposition

3.) by-products of microbial growth and decomposition

4.) a fraction often known as humus where the by-products have undergone alteration into generally more stable forms

This ‘humus’ or stabilised organic fraction, material will often be expected to consist of 50-55% Carbon, 4-5% Nitrogen and c. 1% Sulphur. This is a relatively stable component of the organic fraction which may persist for a number of years within the soil, particularly when in intimate association with components of the mineral fraction, particularly clay and silt sized materials. Table 2-1 below provides guidance on the stability of materials and their persistence in the soil. The light fraction may be broadly described as an intermediate or transitory pool, between fresh residues and the well humified, stable organic matter. The light fraction predominantly consists of plant debris, but may also include fungal hyphen, spores, seeds and animal remains.

2.1.1 The role of SOM for soil quality

Organic additions to soil have long been considered important in maintaining the quality of both natural and managed soils, principally because of their role in providing nutrients and through their role in influencing soil physical properties. In farming systems, before the widespread introduction of manufactured fertilisers organic residues were the only means of adding many nutrients to the soil, in particular Nitrogen. In non-cultivated soils it is likely that more than 95% of the Nitrogen and Sulphur is found in the soil organic matter, and possibly as much as 25% of the Phosphorus.

With the advent of manufactured fertilisers and their widespread use in farming, there has been less reliance upon organic residues as a source of nutrients for plant growth. There are however major differences between organic and inorganic sources of nutrients. In particular organic sources of nutrients often consist of a substantial pool of relatively slow release materials. Release of nutrients from this 'slow release pool' is very variable and is controlled by a.) The nature of the organic materials and b.) The conditions prevailing in the soil. Low ratios of Carbon to Nitrogen and Carbon to Phosphorus tend to result in faster rates of release from these organic sources.

In contrast, SOM can also be comparatively stable at low C/nutrient ratios

It has been a widespread claim, particularly in the field of organic farming that soil organic matter plays a major part in maintaining soil quality. Further, it is frequently claimed that without adequate levels of SOM the soil will not be capable of functioning optimally. In recent years there has also been a recognition that the soil is a major sink for carbon in the overall global carbon cycle, and that maintaining or increasing the carbon held in soils will potentially have a significant impact on the global carbon budget. Table 2-1, based broadly on Stevenson (1994) lists some of the benefits claimed for SOM in soils.

TABLE 2-1: ROLE OF ORGANIC MATTER IN SOIL

Property	Remarks	Effects on Soil
Colour	The typical dark colour of many soils is often caused by organic matter	May facilitate warming in spring
Soil Biodiversity	The organic fraction in soils provides a source of food for a diverse range of organisms. The diversity of the organic materials will generally be reflected in the diversity of the organisms	Many of the functions associated with soil organic matter are related to the activities of soil flora and fauna
Water Retention	Organic Matter can hold up to 20 times its weight in water	Helps prevent drying and shrinking. May significantly improve the moisture retaining properties of sandy soils. The total quantity of water may increase but not necessarily the AWC except in sandy soils
Combination with clay minerals	Cements soil particles into structural units called aggregates	Permits the exchange of gases. Stabilises structure. Increases permeability
Reduction in the Bulk Density of Mineral Soils	Organic materials normally have a low density, hence the addition of these materials 'dilutes' the mineral soil	The lower bulk density is normally associated with an increase in porosity because of the interactions between organic and inorganic fractions.
Chelation	Forms stable complexes with Cu^{2+}, Mn^{2+} and Zn^{2+} and other polyvalent cations	May enhance the availability of micronutrients to higher plants
Solubility in water	Insolubility of organic matter because of its association with clays. Also salts of divalent and trivalent cations with organic matter are insoluble. Isolated organic matter is partly soluble in water	Little organic matter is lost through leaching
Buffer action	Organic matter exhibits buffering in slightly acid, neutral and alkaline ranges	Helps to maintain uniform reaction in the soil.
Cation exchange	Total acidities of isolated fractions of organic matter range from 300 to 1400 $cmol_c\ Kg^{-1}$	May increase the CEC of the soil. From 20 to 70% of the CEC of many soils is associated with organic matter.
Mineralisation	Decomposition of organic matter yields CO_2, NH_4^-, NO_3^-, PO_3^{4-} and SO_2^{4-}	A source of nutrients for plant growth
Stabilisation of contaminants	Stabilisation of organic materials in humic substances including volatile organic compounds	Stability may depend on the persistence of the soil humus and the maintenance or increase of the carbon polls within the soil

Whilst the provision of nutrients is important, the table clearly shows that there are many other soil properties, in particular related to soil physical conditions, which are influenced by the presence of SOM and may indeed be controlled by the presence and amount of SOM. The simple admixture of low density organic material with the mineral fraction will lower the soil's bulk density, but the more significant affects will be related to the influence of SOM on the formation and stability of soil aggregates and the associated pore related properties such as aeration and water flow through soil. The retention and release of water and the ability to provide charged surfaces (variable with pH) where cations may be retained in a form available to plants.

Organic materials in soils have long been associated with the complexing of heavy metals, but recent work reported by the Environment Protection Agency in the USA has suggested that adding composted materials to soil as an organic addition has produced significant increases in the bioremediation of soils contaminated with organic compounds (including herbicides, hydrocarbon products and volatile organic compounds). This increase is both due to the increased amount of organic matter present, and also due to the increased biological activity within the soil due to the fresh pool of organic substrate

Many of the mentioned soil functions and physico-chemical as well as biological reactions associated with SOM (nutrient exchange processes, sorption and buffering ability, physical and hydrologic properties) are well described in basic soil science.

Considerable uncertainty is still claimed when it comes to a distinct valuation of the humus concentration in soil under agricultural or forestry use.

Can we identify a site and management specific optimum SOM content ? And, if yes, would it be justified to establish humus guide values that should be used in extension or other agricultural management programmes (e.g. in implementing *good agricultural practice* and agricultural environmental programmes)?

Based on basic knowledge from soil science it seems justified to define at least ranges of values depending on climate, site conditions, soil, and land use. It could be stated that SOM concentrations below this range would provoke an impairment of soil structure and other soil physical properties, but an excess value could bear the risk of nutrient leaching (nitrate) or undesirable changes of the soil milieu (redox system).

In many cases and soils with a good SOM status those guide values could be achieved by common tools of agricultural soil management (crop rotation, tillage, fertilisation etc.). But management systems resulting negative humus balances, soils with degraded and low SOM status the import of exogenous organic matter specifically in the form of compost must be considered as a mean of soil improvement.

In addition it is necessary to distinguish between the SOM concentration on the one hand and the SOM pool over the soil profile or the relevant soil horizon. This for instance is relevant for the assessment of yield effect and nutrient release dynamics of compost amended soils in field trials.

2.1.2 Forms of soil organic matter

As mentioned above the organic fraction of the soil is diverse, ranging from fresh clearly discernible plant and animal material through to humus where there are no visible signs to indicate the plant or animal from which the material is derived. The organic matter in soils is subject to decomposition; indeed the decomposition of the organic matter is perhaps the key determinant of many of the key roles associated with organic matter in soils. The rate of turnover of the organic materials varies considerably. Table 2-2 presents information on turnover times for some of the key fractions of SOM.

TABLE 2-2: TURNOVER TIME OF ORGANIC FRACTIONS IN SOILS

Organic Material	Turnover Time (y)
Litter/crop residues	0.5 to 2
Microbial biomass	0.1 to 0.4
Macro-organisms	1 to 8
Particulate	5 to 20
Light Fraction	1 to 15
Stable Humus	20 to 1000

It is often difficult to separate the organic residues undergoing decomposition from the soil biota carrying out the decomposition and the humic substances resulting from the processes.

2.1.3 Decomposition of organic materials applied to soil

The decomposition of organic materials in soil is dependent upon: -

- C content, C:N ratio
- Soil temperature
- Soil moisture
- The status of the soil including soil nutrients and pH
- Method of application of the organic residues (soil incorporated> surface applied)
- Rate of application

The decomposition of organic materials in soil is the same whether they are materials naturally added to the soil or materials introduced artificially. The decomposition processes involve a wide range of organisms. Initially the larger organism, such as earthworms and the macro- and meso- soil fauna reduce the amount of material, subsequently the breakdown is performed by the microorganisms. The initial phase of microbial attack is characterised by the rapid loss of readily decomposable organic substances. Depending upon the soil micro-flora and the synthesised microbial cells, the amount of the carbon utilised from the substrate will vary from 10 to 70%. With high C:N ratios the proportions synthesised will be at the lower end of this range. Carbon dioxide will be one of the products lost during this phase. There follows further decomposition of the remaining by-products by a complex series of microorganism. The final material is a stable humus material which will be subject to slow decomposition and additions. The nature of the materials added and the nature of the soil will greatly influence both the rate of decomposition of the residues and the nature of the organic by-products. Where the source material is rich in carbon the rates of decomposition will be slow and there will probably be substantial accumulations of relatively little altered materials. In addition to the influence of the added organic materials, the soil environment also has a major influence, ideally the soil should be moist but not saturated, and the soil should be reasonably fertile with a pH near neutral. If these conditions prevail and the soil is warm there should be optimum conditions for breakdown.

In addition to the nature of the material the mode of incorporation is important in determining the rate of breakdown and production of the beneficial effects associated with soil organic matter. Ideally the materials should be incorporated into the soil so that the soil and organic materials are in intimate association. Where materials are applied as surface dressing the rate of incorporation will most probably be slow, and with heavy applications there may possibly be a sealing effect on the soil restricting fluxes of air and water between the soil and atmosphere.

In making applications of organic residues to the soil it must be recognised that the soil is a living body. The soil system may not be able to function if excessively large single applications are made. Both because of the need to optimise the breakdown process and to optimise the benefits to the soil of the release of readily available nutrients, it is likely that the most appropriate strategy is a small number of applications of residues rather than a single application. The timing of the applications must coincide with the periods when the soil is capable of breaking down the organic additions; cold and wet times of the year should be avoided

The site and soil properties lead to balance between supply and degradation of organic matter. In undisturbed, uncropped eco systems the SOM content is kept on a steady state balance level driven by climate, topography, vegetation, fauna, parent soil material and soil properties, time and the interrelations of all these framework conditions.

Agricultural use disturb this equilibrium and the impact of soil management leads to a constant decrease of SOM (Jarvis et al., 1996[SP2]). Therefore natural, uncropped soils show higher SOM contents followed by grassland and finally arable land.

The new equilibrium is determined by the following basic processes:

1. input of organic materials as there ar dead plant and animal biomass in the soil, organic fertilisers and soil improver
2. mineralisation of SOM
3. export of organic materials, which otherwise would remain on-site (harvested crops and crop residues)

Point 1. and 2. mainly depend on natural factors like climate and soil properties, but also soil management fertilisation. Promotion or inhibition of biological processes, i.e. plant growth and microbial activity are of central importance here. Performance of plant biomass formation as well as the level of microbial transformation predominantly depend on the supply of microorganisms with water, oxygen, nutrients and heat (in the case of plants also light).

Point 3. (export of organic materials) is a pure anthropogenic management factor.

2.1.4 Modelling the transformation of soil organic matter

Several simulation models have been used to consider the incorporation of fresh organic matter into the soil and the dynamics of this material as it maintains the organic soil pools. These models have frequently simplified the process of decomposition and additions to soil pools by identifying a series of broad organic matter pools. These pools are largely conceptual and are controlled by a number of chemical, physical and biological factors which will vary with changes in the environment or as a result of the intervention through soil management. Although the pools identified at the various stages of the decomposition process may represent a grossly oversimplified perception of the various forms of organic matter and indeed the processes involved in transformations between the pools, they do appear remarkably capable of broadly predicting the rate of incorporation of fresh organic materials, the relative sizes of the broad pools and the impact of changes as a result of intervention through management or environmental changes.

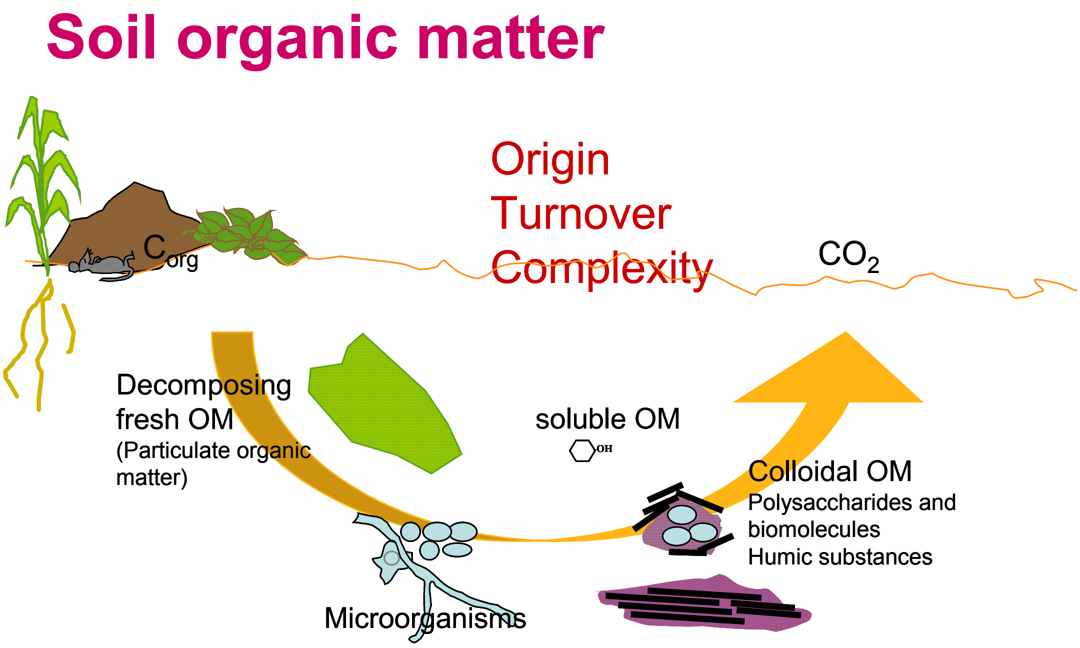


FIGURE 2-1: SOIL ORGANIC MATTER COMPOSITION AND TURNOVER (from Chenu und Robert, 2003[FA3] zit. In Van-Camp et al., 2004)

The model proposed by Jenkinson and co-workers at Rothamsted Experimental Station in the United Kingdom (see for example Jenkinson and Rayner, 1977; Jenkinson 1990; see Figure 2-2), is a simple model which divides soil carbon into three pools, active, slow and passive with different turnover times (2, 50 and 1980 years). The model initially identifies the input materials to be decomposable plant material and resistant plant material, in subsequent stages there are pools of microbial biomass and humus. In addition there is a pool of inert organic matter.

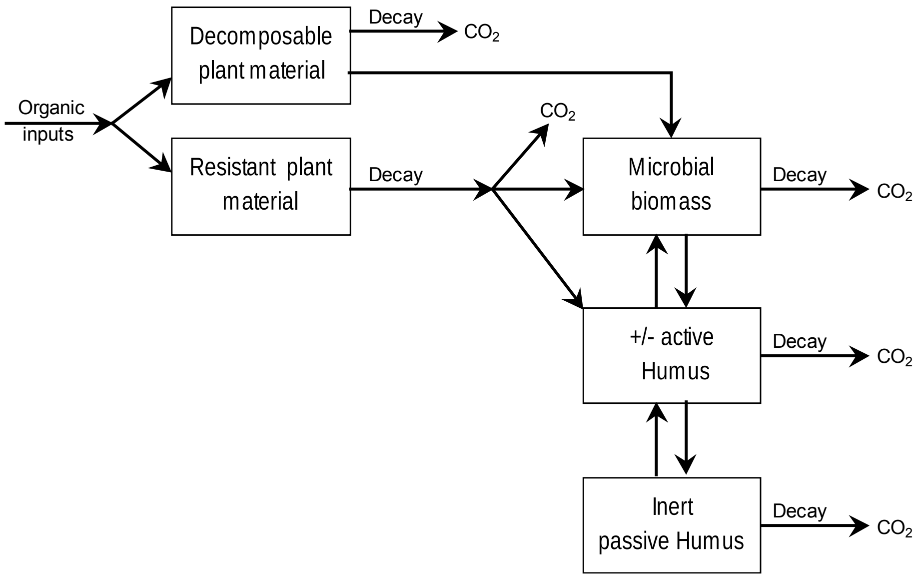


FIGURE 2-2: THE JENKINSON "SOIL ORGANIC MATTER MODEL" (JENKINSON, 1990; SLIGHTLY MODIFIED)

The model of Paul and van Veen (see for example Paul and van Veen, 1978; van Veen and Paul, 1981) developed this simple model further by dividing the plant material into recalcitrant and decomposable fractions and by including the concept of physically protected soil organic matter. Physically protected soil organic matter has a much lower decomposition rate than that which is not physically protected. They suggested further that disruption of the soil as a result of actions such as cultivation or other actions will reduce the physically protected soil organic matter and result in a decline in total soil organic matter levels which is difficult to reverse.

The 'Century *Soil* Organic Matter Model' developed by Paton et al. (1993) uses similar pools to those of the Rothamsted Model and that of Paul and van Veen, but adds the impact of soil texture on processes of soil organic matter decomposition and build up. They model the soil organic matter turnover as being greater in sandier textured soils and the stabilisation of active soil organic matter into slowly decomposable organic matter to be greater in finer textured soils.

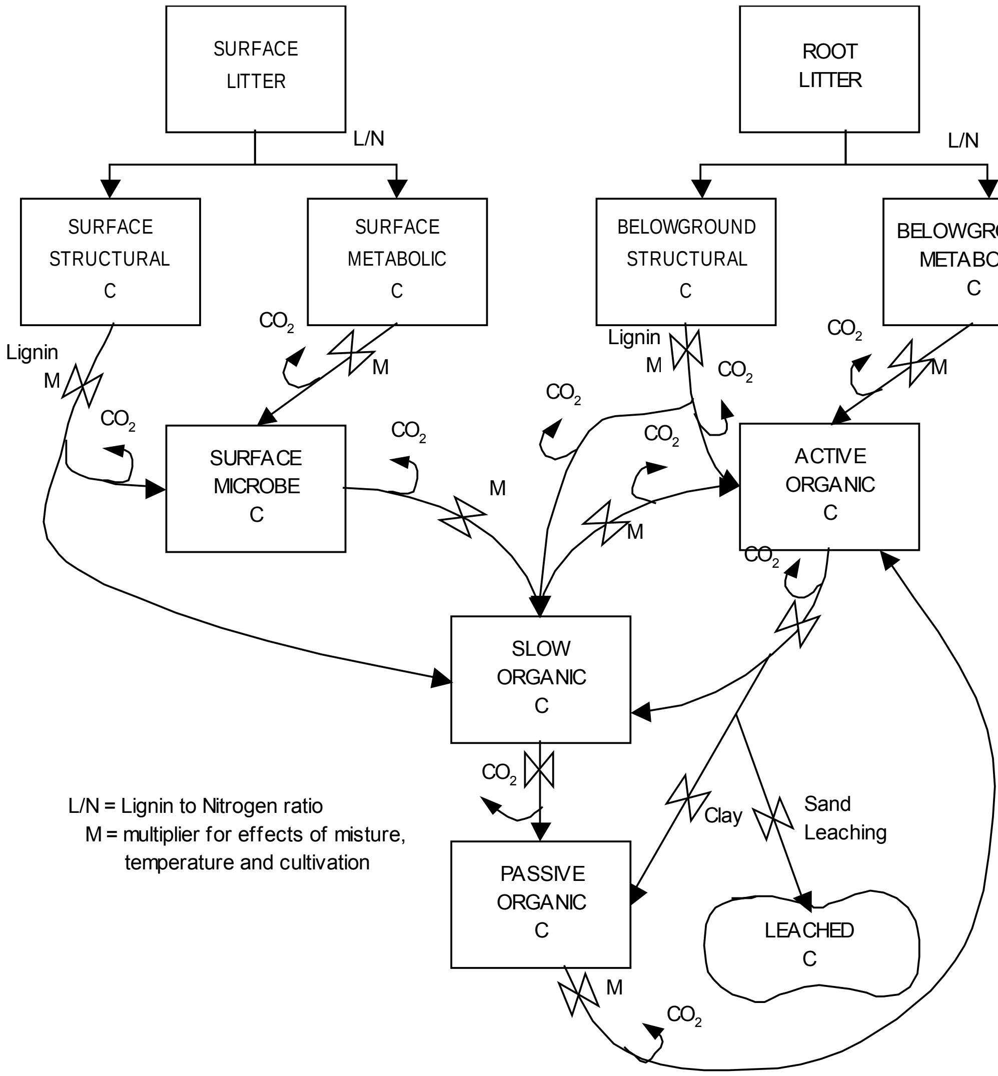


FIGURE 2-3: THE CENTURY MODEL DESCRIBING THE SOM POOLS (MODIFIIED FROM PARTON ET AL. (1993[SP4])

The complexity of the Jenkinson and the Century Model is quite different. The Jenkinson model suits better for describing the general processes, but its simplification a quantification of the material flows is hardly possible. On the other hand the more complex models achieve no significant improvement for the assessment of organic carbon pool changes.

2.1.5 Soil properties influencing the level of soil organic matter

2.1.5.1 Soil texture, parent soil material

Soil texture (particle size distribution) is considered to have a considerable impact on the SOM content (Kuntze et al., 1988[SP5]; Scheffer & Schachtschabel et al., 1998[SP6]).

The significance of the parent soil material can be seen in determining the texture and the associated secondary clay-minerals. The main qualitative differentiations can be summarised as follows:

- Clayey-loamy soils are generally richer in SOM than light sandy soils. The main reasons are:
  - fine textured soils show a reduced gas exchange rates which diminishes the oxygen supply for SOM decomposing organisms; anaerobic milieu conditions can me met more frequently
  - heavy soils tend to a slower warming and consequently less biological activity
  - stable aggregates which are formed inside the fine clayey components are protected against microbial degradation
  - the ability of clay-minerals and aluminium-ferrous oxides to absorb SOM or to incorporate SOM in its structure decelerates decomposition (organo-mineral compounds / complexes)
  - clay-minerals (in particular 3-layer minerals) can absorb extra-cellular microbial enzymes and thus diminish their efficacy of biodegradation.

Following Körschens et al. (1998[SP7]) differences of SOM levels are a function of the concentration of inert C (and N), which again is significantly correlated with the clay content. The range of inert C concentrations in connection with the clay content has been investigated in control plots of several long-term fertilisation trials in Europe. Following the linear regression the C concentration decrease in non fertilised plots down to 0.5% in sandy soils. From clay contents > 30% the C concentration would reach a steady state not below 2 – 2,5%.

Also the decomposable C fraction depends of the clay content. The range between sandy and clayey soil is in this case tighter, between 0,1% (sand) to 0,6% (clay > 30%). This can be explained with the fact that with an increasing clay ratio the (bio)degradation rate for decomposable C fraction is reduced. This phenomenon is also observed in incubation trials which show a clearly slower decomposition of humus associated with clay than for humus associated with sand (Dalal & Mayer, 1986[SP8]; Hassink, 1992[SP9] und 1997[SP10]).

2.1.5.2 Aeration , impact of water

SOM degradation is over a wide range independent of the water content in soil. An inhibition is only observable at water saturation (oxygen deficiency) or extreme dryness. A frequent change of humid and dry conditions promotes the decomposition process.

SOM degradation is inhibited in soils with pronounced bound water (clayey soils), stagnant water (soils with impermeable layers or horizons) or in soils which are influenced by ground water dynamics.

2.1.5.3 pH

Basically, a neutral milieu (pH ± 7) favours biological activity and the transformation of SOM in soils. Within the typical pH range of arable soils between pH 5.5 and 7.5 there is no direct relation between pH and SOM degradation (Scheffer & Schachtschabel et al., 1998[SP11]), i.e. pH increase induced by liming normally does not result in a decrease of SOM. The promotion of higher pH values as a consequence of liming is compensated by increased biomass production (root development. Crop residues)

2.1.5.4 Type and quantity of SOM, microbial Activity

SOM is the substrate of microbial activity. As a rule, soils rich in SOM are more active, transformation processes are performed at higher rates (Rowell, 1997[SP12]).

Furthermore, mineralisation is higher at tighter C/N ratios of the material concerned. E.g. straw from legumes (C/N = 15 - 25) mineralises fast, cereal straw (C/N = 50 - 100) slowly.

It is important to distinguish between organic waste or easily degradable organic materials (crop residues, dead microbial biomass etc.) from SOM compounds of soil itself.

Fresh plant materials enter the soil body as dead plant tissue (leaves, roots) or root exudates continuously during the vegetation period or they are incorporated at certain times of the year as green manure (intercrops, underseeds) or crop residues.

The transformation of fresh organic materials applied to soil is 7 times faster as of soil inherent SOM (Shen et al., 1989[SP13]).

One part of over long time spans well stabilised humic substances show a very low mineralisation rate even at low C/N ratios. Here some typical C/N ratios of several soil types which equally demonstrate a distinct enrichment of SOM in the upper soil layer:

Tschermosem & mull rendzina:	C/N = $10^{-1}2$
Podzol:	C/N = 30-40
Low moor:	C/N = 15-30

These figures show that the C/N ratio might not be the most decisive parameter for the level or degradation of humic substances. However, it would be more adequate to consider the C/N ration of the organic matter as an indicator for SOM degradation status of soils. Especially soils rich in clay but poor in humus may demonstrate a significant discrepancy between the C/N ratio of SOM and the entire soil matrix as an effect of ammonium fixation in clay-minerals.

During mineralisation a continuous transformation of dead organic matter into humic substances takes place. Humus formation can be differentiated in two processes. The microbial re-synthesis, the selective enrichment of hardly degradable substances (waxes, resins, tanning agents) and the direct transformation. This part of the SOM can be defined as inert "*carbon*" or as inter SOM (Körschens et al., 1998[SP14]). SOM represents a continuum of several materials which have reached diverse grades of stability against mineralisation. Those different behaviour patterns towards mineralisation are defined as *organic matter* or *humus pools*. The *stability* is caused by the properties of the molecular structure, the possible physical separation (intra-aggregate area, micro pores) against the soil microbial biomass or by sorption to inorganic soil compounds (clay-minerals).

By chemical/physical fractionising it is possible to separate substances of defined properties. A distinct relation between these fractions of SOM and the C/N transformation has not been approved yet (Paul, 1984[SP15]).

A physical separation in particle size fractions might be more promising. As mentioned above organic associated with san is clearly more accessible to mineralisation than C associated with clay (Dalal & Mayer, 1986[SP16]; Hassink, 1992[SP17] und 1997[SP18]).

2.1.6 Planning organic fertilisation

When organic matter is added to the soil it must be clear what are the purposes of such additions.

The organic additions to the soil will provide the following:

1. A rapid release of nutrients for initial plant growth
2. A pool of slow release nutrients to maintain growth
3. A substrate for microbial activity both for release of nutrients and for development of organic/inorganic relationships so important in the development of soil physical properties.

In planning the programme of additions these broad functions must be considered. There may be parts of the year when the growing cycle of the plants require readily available nutrients, in other times of the year the demand may be to build up the pool of slowly available nutrients. These demands will determine both the timing of the applications and should be considered when determining the nature of the materials to be applied. There may be a need for an initial large input to the soil during the initial phases of restoration, but subsequently after this initial input of organic matter it may be appropriate to have regular additions. These regular additions of fresh material will maintain the activity in the soil system and optimise the beneficial effects of the additions. This is of particular importance where the improvement of the levels of soil organic matter is coupled with the growth of a crop (including trees) where in addition to improving the soil conditions to make the soil robust there is also a need to provide optimal supplies of nutrients and a good environment for plant growth.

2.2 Excursus: the formation of clay-organic compounds and complexes

Together with mineral soil constituents one part of the SOM forms organo-mineral compounds. Clay minerals are the most important ones. These are compounds built of clay minerals in junction with ferric and aluminium oxides with organic substances of diverse structure and molecule size. In the case of *clay-humus-complexes* the organic compounds are *humic substances such as fulvic and humic acids and humic substances*

Clay minerals consist of silicate layers which are kept together by cations or hydrogen bridges. In the layer interspaces and the outer surface elements and substances can be adsorbed or exchanged against other substance and thus released to the soil solution. Consequently they play a major role for the behaviour of nutrients and contaminants respectively. The effective sorption processes are caused be the negative loading of the inter space and outer surfaces. Therefore the so-called 3-layer clay minerals also absorb organic cations like cationic tensides or pesticides. The basic types of 3-layer clay-minerals *Illite*, *Vermiculite* und Smectite are responsible for key properties of several soils, since they are presented in soils in varying quantities and distributions. Other types of clay-minerals (e.g. *caolinite, chlorites*) play a minor role in quantity and for the sorption properties of Middle European soils.

Illite, Vermiculite and Smectite are differentiated by the negative loadings per structural unit andthe type of inter-layer cations. These features are responsible for the swellability of inter-space layers and the ability to adsorb and exchange cations. Vermiculite and Smectite are very swellable and can absorb exchangeable cations to a high extent (*Vermiculite* > *Smectite*). Illite can expand only the outside margin and contribute to a less extent to the exchange capacity of soils.

Also ferrous, aluminium and magnesium oxide are important. They contribute considerably to sorption of heavy metals, phosphate and organic compounds. Not only the quantity, rather the crystalline structure is decisive for the sorption capacity. E.g. amorphous ferrous oxides feature large surface areas and sorption sites accounting for its high reactivity.

The forms of linkage and integration of clay-minerals and organic or humic substances respectively cannot be explained comprehensively. The involved substances and compounds are too complex. Investigations with defined organic materials and clay-minerals allowed to derivate some bond types (Jasmund & Lagaly, 1993[SP19]; Scheffer & Schachtschabel et al., 1998[SP20]; Stevenson, 1994[SP21]). Clay-organic complexes can be formed by:

- Ionic linkage between negative loadings of clay-minerals and organic cations (alcylic groups, amino sugar and acids)
- Ionic linkage between metal complexes of humic and fulvic acids at side surfaces of clay-minerals or ferrous and aluminium oxides
- physical adsorption by van der Waals' forces
- substitution of water molecules in the inter-layer space by neutral organic molecules (*solvation*) with a high *dipole moment*
- exchange of inorganic inter-layer cations by organic cations
- sorption of organic macro-molecules (*polymers*) by hydrogen bridges via H_2O molecules of the exchangeable cations

Ziechmann & Müller-Wegener (1990[SP22]) distinguish clay-humus complexes of 3 variants which a formed in a chronological order:

- Cork like structures in inter-layers and absorbed at clay-minerals surfaces. These are transformation products of humic acids precursors with clay-minerals in the inter-layer spaces with succeeding dislocation of further humification and polymerisation to the clay-minerals surfaces
- Organic matter in the inter-layers only, as a result of the separation of humic substances from clay-minerals surfaces
- Organic matter bound to the outer surfaces of clay-minerals after further transformation with humic substances, which are refused from trespassing into the inter-layers

Besides humic substances also more simple organic compounds such as sugars, alcohols, amino acids, phenols etc. can be adsorbed. The bond strength depends on site (surface or inter-layer space, loading, pKa value (acid dissociation constant), pH, salt content, exchangeable cations etc.).

The formation of clay-organic complexes is encouraged by a high biological activity, because in this case there is a continuous supply of reactive substances which are mixed with the inorganic soil particles.

Thus the import of organic matter indirectly promotes formation of clay-organic complexes by boosting the biological activity and the supply of reactive substances.

Cay-organic complexes influence manifold soil properties. They contribute prominently to soil aggregation and the further physical soil properties linked thereto (see chapter 3.6). Cay-organic complexes stabilise the organic matter in soil. In the inside of aggregates they provide an effective physical protection against oxidation and decomposition by microorganisms and the sorption at clay-minerals as well as ferrous and aluminium oxides provide a better chemical protection against decay (Oades, 1995[SP23]; Tisdall, 1996[SP24]).

This protective function is even strengthened ba y ability of clay-minerals to adsorb enzymes and inhibit their activity (Gianfreda & Violante, 1995[SP25]).

Haider (1995[SP26]) notes, that 50% of SOM is found in organo-mineral compounds, in which the predominant proportion is represented by clay-organic compounds. Thus clay-organic compounds are an important source of carbon and particularly nitrogen mineralisation, because C/N ratio is significantly lower in the clay fraction than the rest of the soil compartments

The impact of clay-organic compounds on the sorption of pollutants must be assessed differentially (see here also chapter 3.8)

E.g. investigations of Rützel et al. (1997[SP27]) have shown diverse results for the adsorption of Cadmium. Though adsorption rates decreased in *Illite-humus* complexes compared to pure *Illite*, it increased in *Montmorillonite-humus* complexes. Celis et al. (1997[SP28]) found a decrease of the adsorption of the herbicide Thiazofluron in *Montmorillonite-humus* complexes against the pure clay mineral.

To what extent an increase of clay-organic complexes supports or inhibits the adsorption of pollutants cannot be answered with distinctness. This depends of a number of further conditions such as types of present clay-minerals, pH, salt content etc. and the individual contaminants concerned.

There is no specific information about the impact on soil management (fertilisation, tillage, cropping systems etc.) on clay-organic complexes in literature. There might be two reasons for this: most investigations focus on humus chemistry and clay mineralogy or concentrate on the difficult measurement of clay-organic compounds,

Basically it can be assumed that the import of organic matter leads to an increased formation of clay-organic complexes, whereas an intensive soil cultivation would have a declining effect.

With the help of new analytical methods (CPMS-^{13}C-NMR technology) a better understanding of the characteristics, formation and transformation of clay-organic complexes may be expected.

2.3 Climatic impacts on SOM

It has long been recognised that the nature of soils and soil formation is controlled by the soil forming factors, as outlined by Jenny (1942). In the same manner the components of the soil, including the soil organic matter, are similarly influenced. A major influence on both the general nature of soils and soil development is the climate, and there are also strong influences on the soil organic matter. The climate will control the biological productivity of the soil, thereby influencing the input of organic matter into the soil system. In addition the once organic materials have been added to the soil as fresh organic matter, the rate of breakdown, the nature of the breakdown products and their stability will be strongly influenced by climate, in particular the amount of precipitation (or perhaps more correctly the duration of the periods when the soil is moist) and temperature. Post et al. (1982) in a review of soil carbon pools on a global scale found the amount of soil organic carbon to be positively correlated with precipitation, and at a given threshold of precipitation to be negatively correlated with temperature. Leith (1973) drew a broad relationship with temperature suggesting that a mean. annual temperature of 15^{o}C was a threshold. When starting at temperatures below this it was suggested increases in temperature will enhance decomposition more than net primary productivity. Carter (1996) reviewed the relationships between climate and soil organic matter levels and turnover, suggesting that wet, cool climates tend to slow organic matter turnover and subsequently favour organic matter accumulation in soil, whilst moist, warm or hot climates favour decomposition. These are of course generalised relationships and will be modified by environmental factors and management.

On a more local scale, Burke et al. (1995) investigated relationships between climate and soil organic matter on a more local scale in Colorado, USA. They noted that higher mean temperatures resulted in lower plant production, higher decomposition rates, lower organic matter storage capacity and associated lower mineralisation rates. Similar contrasts were noted between soils in a given area of different textures; coarser textured soils mirroring the changes with temperature increases when compared with finer textured soils. Results across a wide range of climates from Ladd et al. (1985) for soils of South Australia and Jenkinson and Ayanaba for soils of the United Kingdom and Nigeria, suggest that there will be a doubling of the rate of substrate C mineralisation for an 8-9^{o}C increase in mean annual temperature. The relationship of decreasing soil organic C content with increasing temperature suggests that whilst both decomposition and net primary productivity are influenced by temperature, the influence on decomposition appears to be more sensitive. It is to be noted however that the relationship is probably also influenced by the moisture status of the soil and the quantity and quality of the substrate.

Figure 2-4 demonstrates the geographic-climatic dependence of SOM with a clear gradient in Europe from North(West) to South(East).

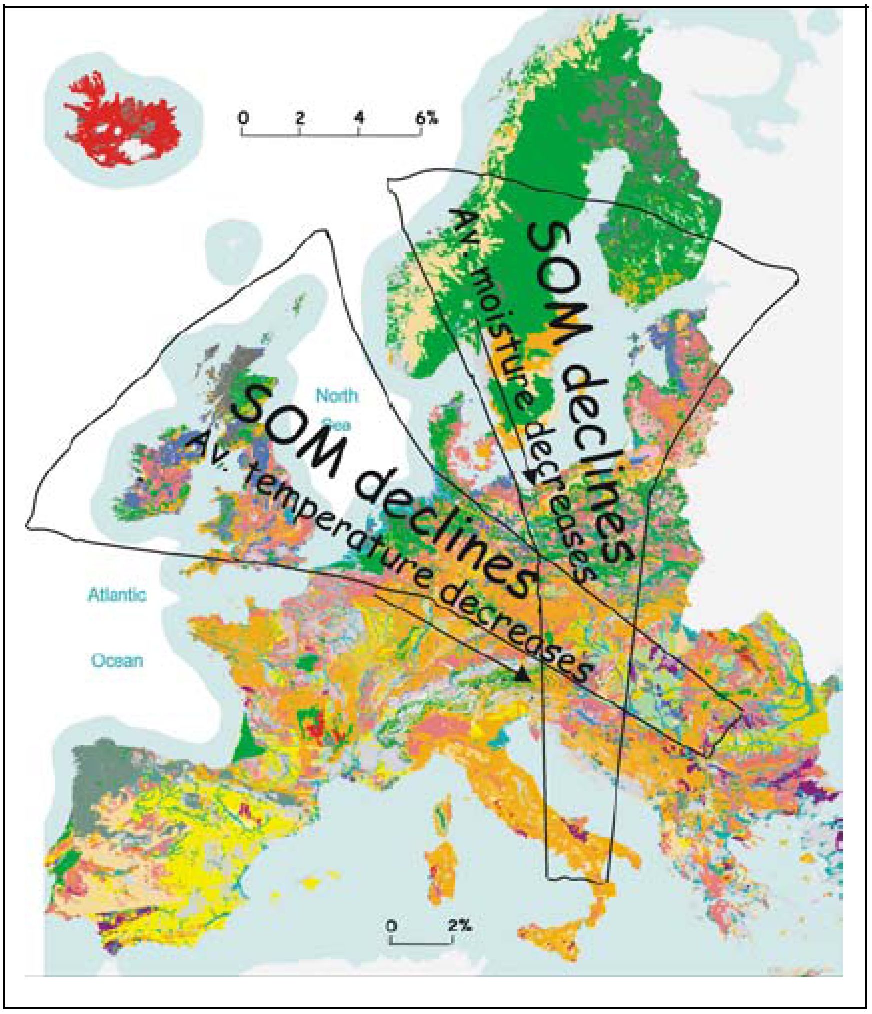


FIGURE 2-4: GENERAL INFLUENCE OF TEMPERATURE AND MOISTURE ON SOIL ORGANIC MATTER CONTENT IN EUROPE (AUS VAN-CAMP ET AL., 2004)

From Figure 2-5, it can be estimated that 45% of the soils in Europe are low (1-2%) or very low (<1%) in organic carbon, and 40% have a medium content (2-6%).

Many of these soils are in agricultural use, and Table 2.3 shows the proportion of Europe estimated to fall into the different organic carbon classes.

From this it can be seen how urgent it is perform an intensive and continuous information on effective and sustainable measures to maintain or enrich SOM in soils under agricultural use

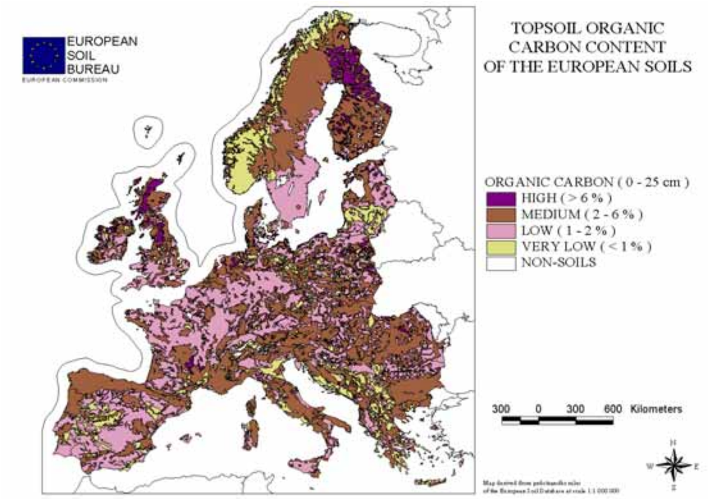


FIGURE 2-5: DISTRIBUTION OF ORGANIC CARBON CONCENTRATION IN EUROPEAN TOP SOILS (VAN-CAMP ET AL., 2004)

TABLE 2-3: ORGANIC CARBON CONTENT OF SOILS IN EUROPE (VAN-CAMP ET AL., 2004)

ha	OC class	OC %	area %
66,558,238	Very low	< 1	13
163,967,166	low	1 – 2	32
230,525,404	**Σ vl + l**	**< 2**	**45**
232,325,106	medium	2 – 6	45
22,173,470	high	> 6	5

One of the key recommendations of the experts report on organic matter was: *“Land-use patterns in areas where the OC Map of Europe identifies soil OC (OM) <2.0% (3.4%) should be critically examined, with a view to proposing changes in land management to stabilise or increase soil OC(OM) levels.”* (Van-Camp et al., 2004)

The following shows that – though to a variable extent – measures to stabilise the humus status of soil are needed in all European countries and climates. Even though methods of sampling and analyses are not always standardised the tendency is evident: SOM management is an issue that has to be followed with care.

TABLE 2-4: PERCENTAGE OF AGRICULTURAL LAND COVERAGE WITH ***VERY LOW*** (< 2%) AND ***LOW*** (2 - 4 %) SOM CONTENT IN SELCTED EUROPEAN COUNTRIES (UTERMANN ET AL., 2004 [FA29])

	% of land coverage of 3 SOM classes		
Land:	**< 2 % SOM** (= <1.2 % C_{org})	**2 - 4 % SOM** (= 1.2 – 2.4 % C_{org})	**Σ < 4 % SOM** (= <2.4 % C_{org})
Austria	14.4	8.2	22.6
France	11.6	25.4	37.0
Germany	41.6	8.9	50.5
Ireland	4.6	3.0	7.6
The Netherlands	20.0	23.1	43.1
Estonia	---	73.2	73.2
Latvia	---	35.1	35.1
Romania	62.5	11.3	73.8

2.4 Topography, relief

Chapter 2.3 describes the direct influence of climatic conditions on the metabolism of SOM.

Topography and relief have a more indirect impact, by altering micro-climatic (temperature, humidity) conditions. E.g. soils in higher locations are exposed to cooler and more humid conditions than neighboured lower sites of the same region. This can occur already after little altitude difference. South exposed soils frequently show higher SOM decomposition rates than those of north exposure. On the other hand south exposed sites may be affected by higher evaporation rates which leads to water deficiency and as a result would inhibit microbial degradation. Thus, the circumstances depend on the site specific overall climate conditions which may inverse the effects (Kuntze et al., 1988[SP30]; Scheffer & Schachtschabel et al., 1998[SP31]; Rowell, 1997[SP32]).

Slopes may contribute to erosion and subsequently change the SOM contents of arable soils. As a result of the run-off of fine-grained and humic soil particles the SOM stock of the upper slope in the A_p-horizon declines. Downhill a colluvium is formed with a relative mighty humus horizon in the top soil. This development is further supported if growing conditions are favourable down the slop and compared to the eroded parts more root and crop residues contribute to the organic matter enrichment (Burke et al., 1995[SP33]).

In depressions or valleys under the influence of the groundwater soil aeration might be reduced, which induces humus accumulation. The developing half-bog or bog soils are sometimes cultivated.

2.5 Long Term Management and Soil Organic Matter levels

It is well known that soils change through time, it is also recognised that soils will change in response to agricultural management. It is not surprising therefore that soils under long term agricultural management will also show changes. These changes may vary in relation to both the nature of the management and the length of time under a particular management or combination of management practices. In a number of places around the world there are long term agronomic trials where the soil has been subject to the same management for many years. Mitchell et al. (1991) reviewed the status and outcomes from long term agronomic research. When many of these long term experiments were undertaken the principal source of nutrients to meet crop demands were from manures, and management systems would often include fallow years and legumes as part of the rotation to increase the input of nitrogen.

The Morrow Plots at the University of Illinois were established in 1876 to consider different rotations and land management practices. Results from the first 64 years were reviewed by Stauffer et al. in 1940. Table 3 illustrates the changes in soil organic matter on three rotations with two contrasting managements. A comparison is also made with the adjacent uncultivated land.

TABLE 2-5: CHANGES IN SOM ON THREE ROTATIONS WITH TWO CONTRASTING MANAGEMENTS (MORROW-PLOTS AT THE UNIVERSITY OF ILLINOIS)

Rotation	Treatment	% organic matter after 64 years	% change
Corn	None	2.99	-45.6
	Manure-Lime-Phosphorus	3.59	-34.7
Corn - oats	None	3.68	-33.1
	Manure-Lime-Phosphorus	4.20	-23.6
Corn – oats – clover	None	3.92	-28.7
	Manure-Lime-Phosphorus	5.76	+4.0
Uncultivated site		5.50	0.0

These figures show that with no treatments there is a marked decline in SOM. They also show how different crop rotations introduce variability in the response to manure-lime-phosphorus treatments. Guernsey et al. (1969) in reviewing the results from the Morrow Plots concluded that in addition to the decline in SOM continuous corn without any manure or fertiliser additions resulted in lower yields, increased bulk density, reduced porosity and reduced aggregate stability on this silt loam soil. These changes however were only reflected in the soil properties in the upper 25 cm.

In a similar study of a long term cropping experiment at Sanborn Field at the University of Missouri established in 1888, Buyanovsky et al. (1996) noted that there was a marked relationship between the decline in SOM and the number of times the land was tilled. They also noted that manure applications of 15 Mg ha^{-1} a –1 with no fertiliser applications, seemed to maintain SOM levels corn and wheat as the rotations. Buyanovsky and co-workers also noted the recovery on the SOM content when a change of policy occurred and residues were returned to the soil following 36 years of complete removal. The SOM was still showing evidence of increase some 50 years after this change of management policy.

A similar long term experiment has been in progress at Rothamsted Experimental Station in England since the 19th Century, with changes in management from grass to arable and long term arable management. Johnson (1991) reports the following general trends in SOM. On the soil ploughed out from grass the SOM level declined steadily but after 36 years it was still not as low as that in the old arable soil retained in arable cropping. With changes in the sward management there had been an increase in SOM in the grassland soil. In the arable soil laid down to grass the SOM levels were still below the continuous grassland even after 36 years of grass. Computations suggest that it will take at least 100 years from the equilibrium SOM content of the arable soil converted to grass to reach the same level as the long term grassland plot on the silty clay soil. Johnson also notes that the SOM levels on the sandy soils of the Woburn Experiment close to Rothamsted were lower than the silty clay soils at Rothamsted under all treatments. Thirty years of continuous arable cropping resulted in marked declines in SOM levels on all treatments although the initial SOM was less than 2% at the start of the experiment. Interestingly there has been no marked reduction in yield.

The long term trials in Rothamstead show that only the recycling of manure contributes to a maintenance or increase of the SOM level.

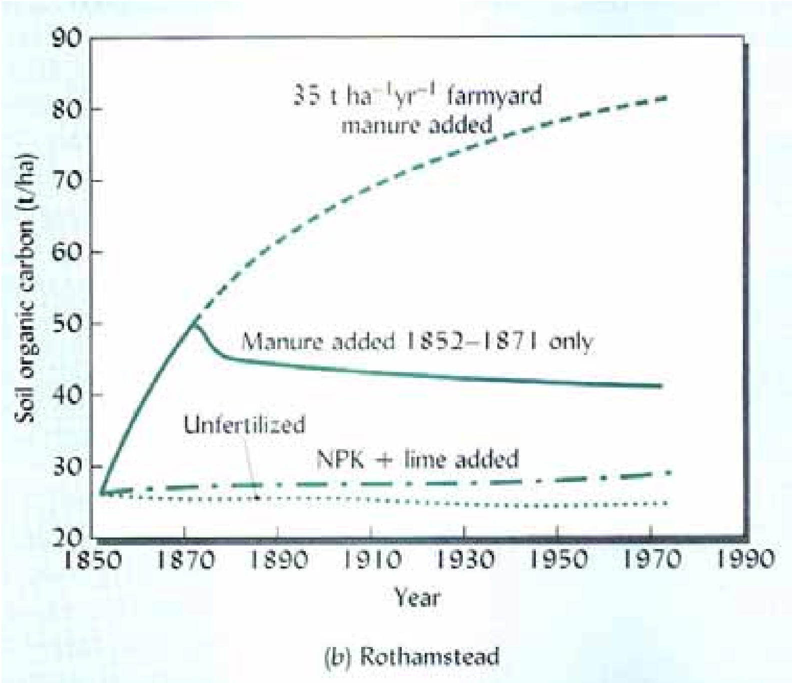


FIGURE 2-6: PERMANENT TRIALS ROTHAMSTEAD: IMPACT OF THE FERTILISATION SYSTEM ON THE DEVELOPMENT OF THE SOM STATUS

Using data from 13 sites across Europe, Körschens et al. (1998) reviewed the turnover of SOM. They concluded that in considering organic matter in soil it was important to consider at least two fractions, a relatively inert fraction which is barely involved in the organic matter dynamics except over periods of many years, and a decomposable fraction. The behaviour of this decomposable fraction will depend both on soil and on management. Generally the rate of loss of SOM during cultivation is more rapid on sandy textured than on clay textured soils. Conversely sandy textured soils generally show a more rapid increase in SOM levels when management involves additions of organic materials, whether manures, composts or plant residues. They also noted a marked relationship with SOM levels and crop yields. Given the current concerns about nitrogen losses to groundwater and to the atmosphere through gaseous emissions, Körschens and co-workers noted that soils with a high SOM must be carefully managed to avoid nitrogen losses.

Not all the changes in SOM as a result of land management have been negative. Nieder and Richter (2000) report results of monitoring Carbon and Nitrogen levels in soils of Germany between 1970 and 1998, during which time there had been a planned increase in the depth of ploughing, from a previous practice of <25 cm to a new practice of ploughing to >35 cm. They noted that this increased depth of ploughing had prevented the leaching of surplus nitrogen and other nutrients because the deepened depth of cultivation was re-establishing the SOM equilibrium in the 0-35 cm depth. Nieder & Richter (2000) suggest that for the majority of loess soils the equilibrium will be reached in the early part of the 21st Century, and at this point care must be taken in managing nutrient applications because the soil will no longer have the buffering effect of the ‘build up’ process. At this point careful management must match the inputs of nitrogen and other nutrients to the export in harvested crops. This is particularly important on the coarser textured soil where change is likely to be more rapid and the vulnerability to leaching greater.

In Therwil, Switzerland the DOC trial (bio-Dynamic, bio-Organic, Conventional) between 1978 and 1998 has compared three land management strategies that differed principally in terms of the amount and form of fertilisers and the plant protection strategies adopted, with a no fertiliser treatment and a conventional mineral fertiliser treatment (Fließbach et al., 2000a; Fließbach et al., 2000b). Tillage operations were standard across the plots and a seven year rotation prevailed consisting of:

2 years grass/clover – 1 year potatoes – 1 year winter wheat – 1 year cabbage/beetroot – 1 year winter wheat – 1 year winter barley (after two rotations this was replaced with grass/clover)

The three major treatments were compared with a no-fertiliser treatment (**NOFERT**), and a conventional treatment using only mineral fertilisers (**CONMIN**).

Major Treatments:

bio-Dynamic (BIODYN): No mineral fertiliser; Manure and slurry of 1.2 livestock units ha^{-1} per year (after 1994 1.4 units ha^{-1} per year); Aerobically composted manure; Mechanical weed control; Indirect plant disease control; Plant pest control with plant extracted bio-control agents; Biodynamic preparations for plant protection

Bio-Organic (BIOORG): Small amounts of mineral fertiliser; Manure and slurry of 1.2 livestock units ha^{-1} per year (after 1994 1.4 units ha^{-1} per year); Rotted manure; Mechanical weed control; Indirect plant disease control (copper until 1992); Plant pest control with plant extracted bio-control agents

Conventional (CONFYM): Mineral Fertilisers – 1978-91 120% of official recommendations, after 1991 – 100%; Manure and slurry of 1.2 livestock units ha^{-1} per year (after 1994 1.4 units ha^{-1} per year); Rotted stack manure; Mechanical and herbicide weed control; Plant disease control using fungicide to threshold levels; Plant pest control with insecticides and plant extracted bio-control agents; Growth regulators in cereals

After three rotations there were distinct patterns in terms of pH, organic C and microbial biomass. The results for samples taken from 0 to 20 cm, are presented for pH ($CaCl_2$), Organic Carbon (%) and microbial biomass (expressed relative to the mean value for CONFYM). These results are presented in Table 2-6.

TABLE 2-6: PH, C_{ORG} AND RELATIVE MICROBIAL BIOMASS IN 1998 IN THE DOC TRIALS AFTER 21 YEARS / 3 CROP ROTATIONS 1998 (FLIEßBACH ET AL., 2000A; FLIEßBACH ET AL., 2000B)

	pH ($CaCl_2$)	%organic C	Microbial Biomass relative CONFYM [%]
NOFERT	5.27	1.30	80.4
CONMIN	5.11	1.41	75.8
BIODYN	6.12	1.69	138.6
BIOORG	5.83	1.55	123.0
CONFYM	5.56	1.49	100.0

These results show a clear trend of increased soil organic matter and microbial biomass with the management strategies involving cycling of added organic materials, which continued the trends reported in the earlier stages of the trials.

3 EFFECTS OF COMPOST FERTILISATION SYSTEMS ON SOIL ECO SYSTEM AND PLANT PRODUCTION

3.1 Compost fertilisation and soil organic matter (humus)

3.1.1 Examples of humus reproduction through compost fertilisation

Key elements on the central role of SOM for eco-systems and plant growth have been given in chapter 2. The increase of humus content by compost application is documented in numerous papers (Bohne et al., 1996[SP34]; Buchgraber, 2000[SP35]; Hartl et al., 1999[SP36]; Parkinson et al., 1999[SP37]). With the supply of an average of 5 – 10 Mg d.m. compost corresponding to 1.5 – 3 Mg organic matter the humus decomposition caused by cultivation measures can be balanced, respectively the C content of the soil will be increased by a long-term compost application(Gutser, 1999[SP38]).

Based on a 6 year field test on a sandy loam soil Gutser (1996) computed the highest *“humus reproduction coefficient”* (K_{HR} : Mg Humus-C / Mg fertiliser-C) for compost (40% of total fertiliser C is bound to humus-like substances) as compared to other organic amendments. In the same experiment the C_{tot}-concentration increased from 1.36 by 0,5 % to 1,86 % (Table 3-2.

TABLE 3-1: ORGANISCHE SUBSTANZ UND C/N-VERHÄLTNIS IN KOMPOSTEN [EIGENE ERHEBUNGEN AN ÖSTERREICHISCHEN BIOKOMPOSTEN]

		Unit	n° of samples	10% percentile	25% percentile	*MEDIAN*	75% percentile	90% percentile
org. matter	OS	% TM	220	20.6	25.1	***31.0***	36.3	44.2
total org. carbon	TOC	% TM	219	11.9	14.6	***17.9***	21.1	25.7
C/N-ratio			201	10.9	11.7	***12.9***	14.4	16.0

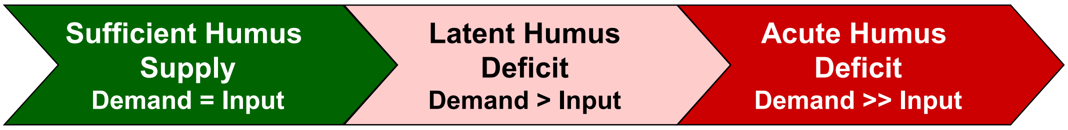
On account of the usually differing properties of organic substances of compost and SOM a long term compost fertilisation system leads to a qualitative change of the SOM pool. The portions of aromatic C and Lignine are rising. The humification degree of SOM drops after compost application and can lead to a reduced stability of the SOM (Mayer 2003[SP39]).

TABLE 3-2: HUMUS REPRODUCTION OF DIFFERENT ORGANIC SOIL AMENDMENTS (GUTSER, 1996)

fertiliser	**K_{HR} 1)**	**org. fraction fertiliser**		**total solid matter**	
		C/N	C/P 2)	C/N	C/P 2)
sewage sludge	**0.15**	7 - 10	80	3 - 9	14
slurry	**0.20**	14 - 16	170	7 - 9	35
manure	**0.30**	14 - 18	450	12 - 15	90
compost	**0.40**	15 - 23	800	13 - 20	80

1) K_{HR} : Mg humus-C/ Mg compost-C; Kundler, 1986 [SP40]; 2) orientation values (∅)

The question of humus reproduction by compost use was pursued by Reinhold & Körschens (2004) und Reinhold (2005[FA41]) together with the Federal Quality Assurance Organisation Compost (BGK e.V.) in Germany. The results were summarised in “Organic Fertilisation – Basics of Good Practice” issued within the series *Compost for Agriculture* published by BGK e.V. and the Federal Research Institute for Agriculture (FAL) (BGK e.V., 2005[FA42]). Besides the estimation of the humus consuming or humus supplying implications of crop rotations and more or less preserving soil cultivation methods *crop residues* or the *supply of organic fertiliser and soil improving measures (compost)* are most important tools for balancing the humus demand. It is claimed that the question of fertilisation to maintain soil fertility should be connected to the amount of humus supply.



A further point is the efficiency in humus reproduction and replacement. Humified organic matter will especially contribute to humus formation.

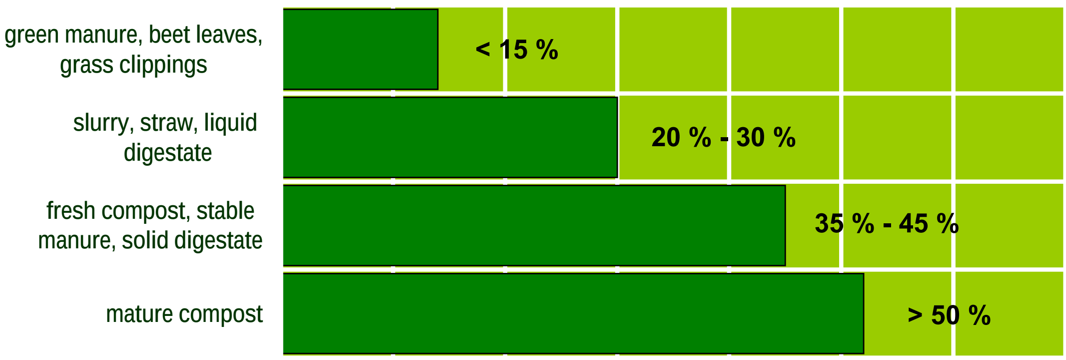


FIGURE 3-1: PROPORTION OF ORCANIC CARBON CONTRIBUTING TO *HUMUS REPRODUCTION ON DIFFERENT ORGANIC FERTILISERS* (BGK E.V., 2005)

For the humus reproduction efficiency of an organic fertiliser the proportion of humus-C is of decisive importance. This is the portion which can be credited for the humus formation respectively for the humus replacement. The following table characterises the humus-C portion and the resulting humus-C reproduction.

TABLE 3-3: HUMIFIED ORGANIC CARBON ON ORGANIC FERTILISERS (BGK E.V., 2005)

Organic fertiliser	**Organic matter (d.m.) 1)**	**Organic carbon (d.m.) 2)**	**Percentage of humus-C 3)**	**Humus-C reproduction 4)**
Mature compost	36%	21%	51%	2,6 Mg ha^{-1}
Liquid manure (pig)	75%	43%	21%	0,1 ha^{-1}
Straw (cereal)	85%	49%	21%	0,6 ha^{-1}
Green fertilising, beet leaves	90%	52%	14%	0,5 ha^{-1}

1) Volatile solids in % of dry matter

2) Organically bound carbon in % of dry matter (calculated from volatile solids x 0.58), to be determined more exactly from direct C-analytic

3) Portion of effective humus-C at the organically bound carbon, according to Reinhold, (2005)

4) Humus reproduction at medium fertilisation rates: compost (40 Mg ha^{-1} in 3 years), pig slurry (30 m^3 ha^{-1}), straw 87 Mg ha^{-1}), green manure/beet leave (60 Mg ha^{-1}). Assumption: typical mean dry matter contents for all materials.

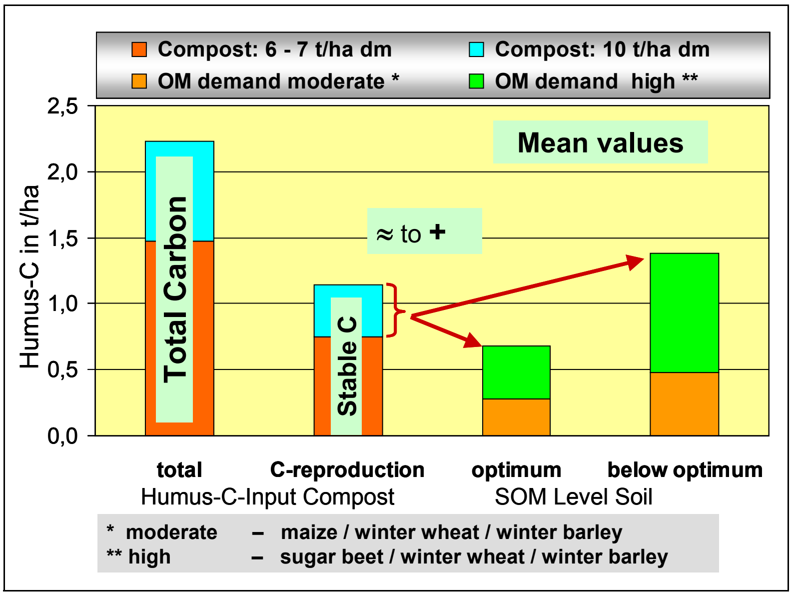


FIGURE 3-2: COMPARISON OF COMPOST-C SUPPLY BETWEEN REQUIREMENT OF THE SOIL AT A MEDIUM AND HIGH HUMUS DEMAND DEPENDENT ON THE CROP ROTATION AND HUMUS SUPPLY (KLUGE, 2006)

The balance of humus demand which can be calculated from humus consumption and supply is summarised in Figure 3-2 (Kluge, 2006). From this results that with a compost application between 7 and 10 Mg d.m. per year an average of an even to positive humus balance can be achieved.

Regular compost application increases the humus content of the soil slowly but measurable in the long run. The tests summarised in chapter 3.1.3 report a relative enrichment of 9 – (478) % OM dependent on application rates, soil, the period of examination and the cultivation practices. The average increase of the humus content in the compost plots of various trials was 0.1 – 1.9% points, while a decrease of the humus content could be assessed without organic fertilising. A few examples are described here in more detail.

After 9 years testing 4 different composts (annual compost application corresponds to 175 Kg N-supply) Aichberger et al. (2000[SP43]) found a humus increase from 1.9 % to 1.98 up to 2.13 %. The maximum increase contrary to a calculated increase to be expected of 0.5 to 0.8% in practice was found to be 0.3 %. From this was concluded that the calculatory difference was mineralised over time. Pure mineral N-fertilising led to a SOM depletion of 0.06, 0.12 und 0.2 % at 40, 80 resp. 120 Kg N $ha^{-1}yr^{-1}$. The authors assume that compost is a fertiliser stabilising humus respectively stimulating stable humus formation.

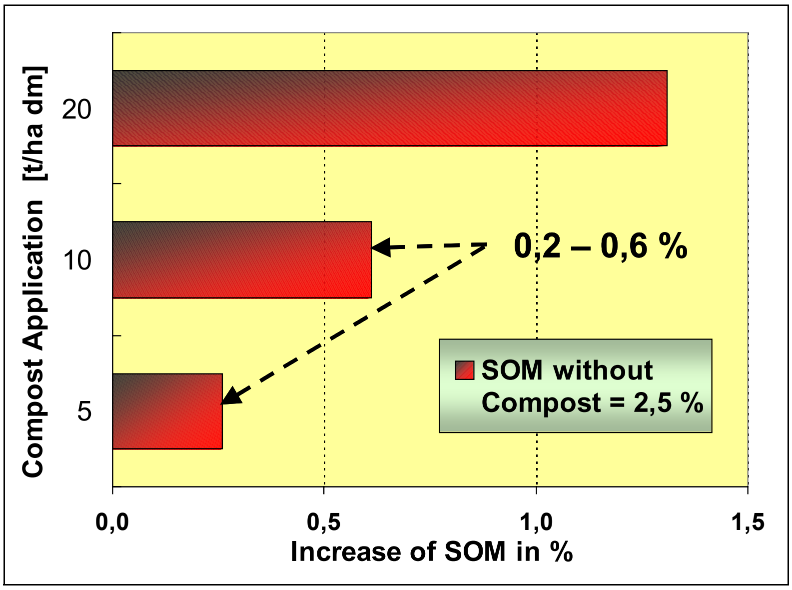


FIGURE 3-3: ANHEBUNGEN DER HUMUSGEHALTE NACH 9 BZW. 12 VERSUCHSJAHREN MIT KOMPOSTAUFBRINGUNG IM MITTEL ALLER STANDORTE BEI KOMPOSTGABEN VON JÄHRLICH 5, 10 BZW. 20 MG HA^{-1} TM (KLUGE (2006[FA44])

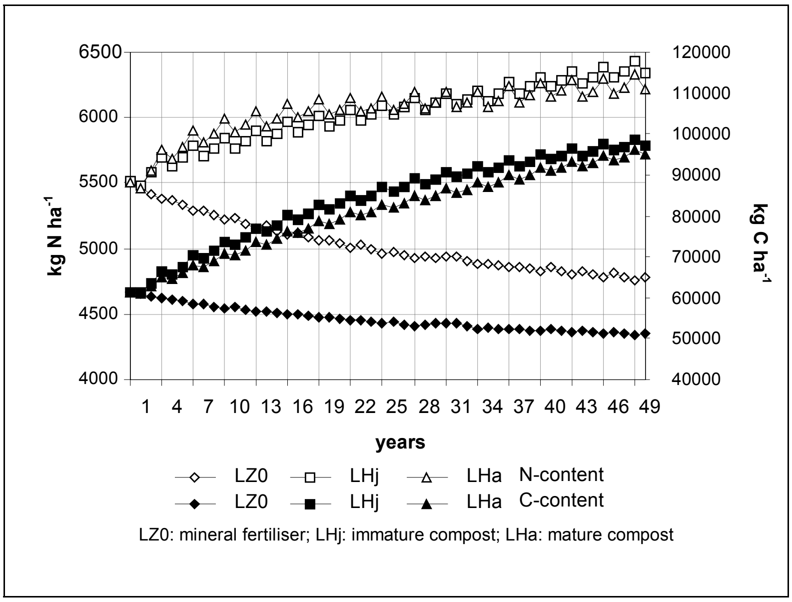


FIGURE 3-4: MODEL (DAISY) FOR C AND N PERFORMANCE DURING 50 YEARS WITHOUT AND WITH COMPOST APPLICATION (30 MG F.M. HA^{-1}3Y^{-1}) (STÖPPLER-ZIMMER ET AL., 1999)

During a period of 9 resp. 12 experimental years and on an average of different locations Kluge (2006[FA45]) ascertained an increase of humus content of 0.26, 0.61 resp. 1.31% at a compost application of annually 5, 10 resp. 20 Mg ha^{-1} d.m.. This is an increase of 10%, 24% or 52% compared the control without compost application. With an average compost application of 6 to 7 Mg d.m. per ha and year a humus supply was calculated of 2.5 to 3 Mg ha^{1}a^{1}.

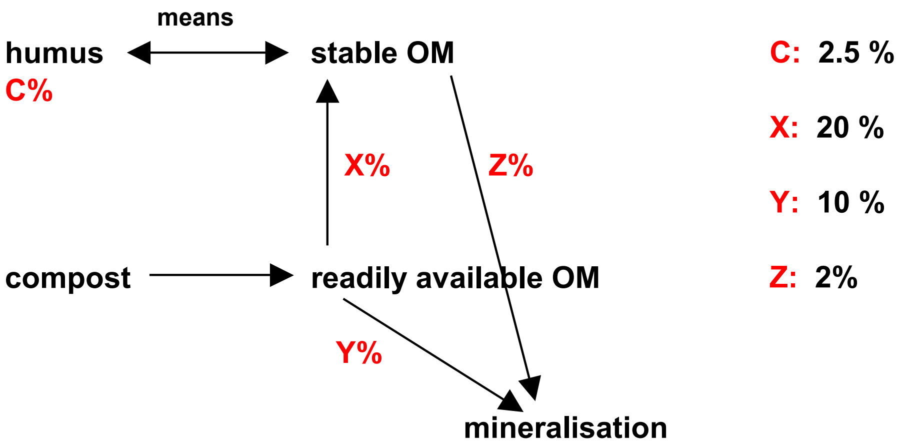
This increase of SOM through compost fertilisation is confirmed by many authors (e.g. Bohne et al., 1996, Buchgraber, 2000 Hartl, 1999, Parkinson et al., 1999).

In correspondence with most long term researches (e.g. Diez & Krauss 1997[SP46], Gutser & Ebertseder 2002[SP47], Buchgraber 2002[SP48]) a medium-sized increase of humus content of 0.1 to 0.2% can be anticipated. It can be concluded, with applications of 6 – 7 resp. up to 10 Mg ha^{-1} d.m.. the reproduction of the SOM is guaranteed according to Timmermann et al., 2003[SP49], even a positive balance usually exists which is reflected in the gradual increase of the humus content.

Another clear picture of the effect of compost fertilisation is shown in the Swiss long-term field trial, where conventional fertiliser systems have been compared with bio-dynamic and organic-biological fertiliser and cropping systems (see Table 2-5)

Modelling (computer simulation-model DAISY, Stöppler-Zimmer et al., 1999) long term compost management (loamy soil, compost: 30 Mg d.m. ha^{-1} 3y^{-1}; crop rotation: sugar beet – winter wheat – winter barley, followed by rape as intercrop) vs. mineral fertilisation over a period of 50 years, showed declines in the N- and C-levels in the inorganically managed sites and increases with compost fertilisation. The C/N ratio became wider with the duration of compost application (Figure 3-4).

Hogg et al. (2002[FA50]) calculated a model for potential C-sequestration in compost amended soils The model is based on the following basic assumptions:



C% ... Initial value of SOM

X% ... OM incorporated with compost which is transferred in the stable organic soil pool

Y% ... The available OM portion incorporated with compost which is subject to mineralisation

Z% ... OM portion of the „SOM-pool“ which is mineralised, however, at to a distinctly minor extent than the one which originates from compost.

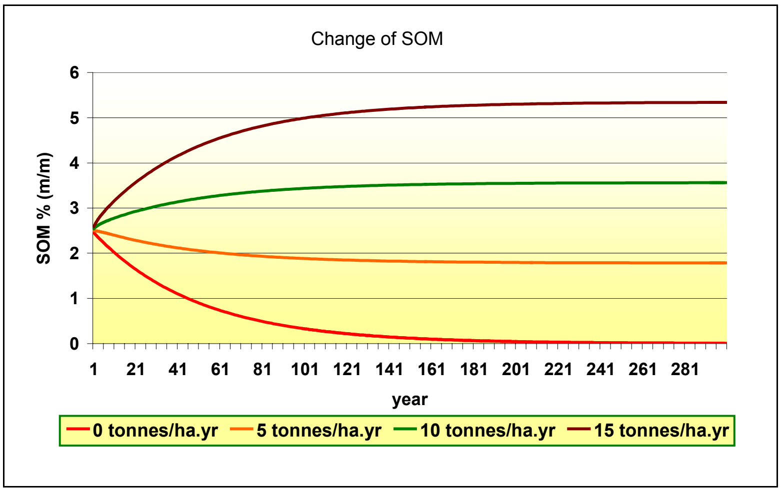
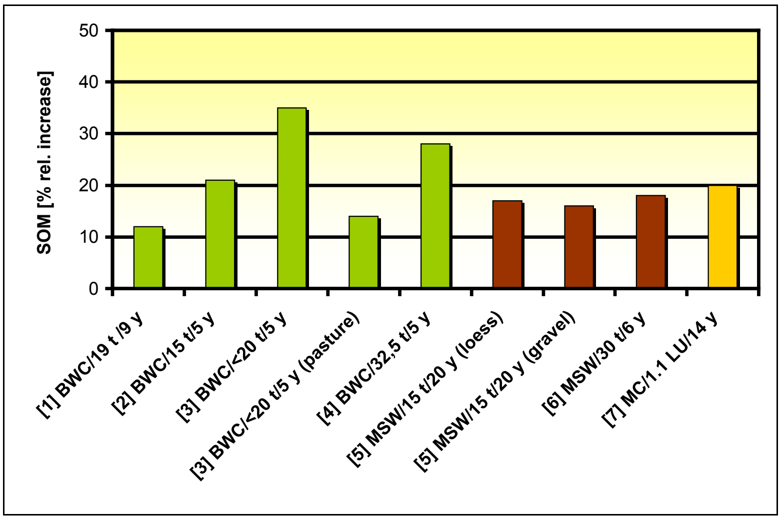


FIGURE 3-5: EFFECT OF DIFFERENT RATES OF COMPOST APPLICATION ON SOIL ORGANIC MATTER LEVELS (FOLLOWING A MODEL BY HOGG ET AL., 2002)

The change of SOM, which induces a regular compost fertilisation over the years, is therefore dependent on the assumptions for the parameters X, Y and Z, from the initial concentration and the compost quantity applied.

Half-life values for the mineralising rate (Z) are given for soil humus from decades to several 1.000 years. By this different values for the annual mineralisation are obtained.

Our example shows typical values for the moderate continental climate: X = 20%, Y = 10%, Z = 2% (half-life value ca. 35 years at a relatively low initial background concentration of 2.5% SOM).



BWC…biowaste compost; MSW…solid waste compost; MC…manure compost; LUlifestock units per ha; '19 Mg' … 19 tonnes f.m. compost per ha*year

Daten von Aichberger et al., 2000[SP51]; Bragato et al., 1998[SP52]; Buchgraber, 2000[SP53]; Hartl & Wenzl, 1997[SP54]; Diez & Krauss, 1997[SP55]; Businelli et al., 1996[SP56]; Alföldi et al., 1995[SP57]

FIGURE 3-6: RELATIVE INCREASE OF SOM IN COMPOST AMENDED SOILS IN SEVERAL FIELD TRIALS

The organic matter content in compost is 35%. Furthermore different application quantities are compared: 0, 5, 10 and 15 Mg d.m. $ha^{-1}a^{-1}$ over a period of 300 years. Referring to the made assumptions a light increase and stabilisation of the SOM may not be achieved below ca. 10 MG d.m. $ha^{-1}a^{-1}$.

Figure 3-6 summarises some examples of the relative increase of the humus content through regular compost fertilisation.

3.1.2 Summary considering the conclusions of he symposium "Applying Compost – Benefits and needs"

All of the long-lasting compost field trials result in an increase of SOM. The essential influencing factors for SOM-enrichment are quantity, type and degree of humification of compost and the soil properties (soil type; clay content). Mature compost achieves a higher increase of SOM. There are trials which show no significant differences in SOM at varying C-sources (straw, manre, compost) but the majority of field experiments have proven a better humus reproduction for composted materials. The type and quantity of crop residues which stay on the field must be considered, too. Laboratory conditions show a medium-term C-mineralisation of only 1 to 20% of the applied compost C_{org}. This proves that compost fertilisation contributes to enhanced carbon sequestration in the soil and thus to climate protection (see chapter 3.2).

A positive correlation of compost fertilisation and the connected increase of SOM to an enhanced microbiological activity of soils can frequently be found. (Mäder, 2003).

However, the assessment of long-term fertilisation trials, according to Körschens (2003), show a relatively small variability of the degradable C_{org} e.g. with manure of 0.2 to 0.6 %. The result is dependent on the clay content in the soils. The humification rate in clay soils is double as high as in sandy soils, whereby the composition of SOM and stability is researched insufficiently.

Thus the question arises, what is the more specific intention and objective of the application of organic carbon when addressing short- and long-term benefits for the soil functions. The definition and understanding of those specific benefits (change of functional SOM pools, dynamic of C-N fixation and mobilisation contribution to stabilise the soil food web, change of microbial and active nutrient mobilisation etc.) needs certainly further basic and applied research.

A country-wide test in France pleaded for compost as a supplementing C-source considering a minimum content of C_{org} in the soil of 1.1 to 1.5% besides the return of crop residues and manure (Le Villio et al., 2003[FA58]).

Regulations for compost utilisation in agriculture should in any case offer sufficient flexibility in order to achieve both the short-term effects (e.g. increase of microbial metabolic efficiency) and the long-term aims (soil improvement by preservation and increase of the humus pool). The local conditions (soil properties, climate, water balances, soil utilisation and crop rotation) must be considered adequately.

In order to increase efficiency of compost utilisation a better understanding of the effective functional properties of composts in relation to composition of input materials and composting process is needed. Among others here exists a demand of innovative analytic methods for the characterisation of the behaviour of the organic matter applied with compost (contribution for a middle-term humus reproduction, mineralisation potential under different site and management conditions).

3.1.3 Compost fertilisation and soil organic matter – tabular survey

TABLE 3-4: COMPOST FERTILISATION AND SOIL ORGANIC MATTER – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Aichberger et al., 2000[SP59]	Field trial 1991 – 1999; FF: KM-SW-WG; random. Block, 4 replications loamy silt	BWC, GWC,CM, SSC; Basis: 95 resp. 175 Kg N ha^{-1}; + 80 Kg N ha^{-1} from NAC (Nitramoncal) on Corn-M, 60 Kg on cereals, 0-40-80^{-1}20 kgN ha^{-1} mineral (NAC), Standard = 80 Kg N ha^{-1}	Average increase of SOM on the Comp plots 0,1 – 0,3 %-points (equivalent to 12 % relative enrichment in comparison to the original content). By calculation the enrichment would be 0,5 – 0,8 %-points.	Humus ↑
Alföldi et al., 1995[SP60]	Longterm field trial since 1978; Comparison organic-dynamic (D), organic (O) conventional (K) and mineral (M) cultivation (DOK-experiment) random. block; 3 plots (3 crops parallel; 4 replications. 4 systems of cultivation, 2 fertilisation steps (96 plots) lessivé on loess CR: Pot, W-W, BR, W-W, B, 2x Ley	Input of org. matter during 7 years (2nd CR-period): (D1): 1010 Kg ha^{-1}; (D2): 2.020 Kg ha^{-1} as CM Results at the end of the 2nd CR-period; (O1) & (O2): RotM; (K1) & (K2): StabM ca 1.000 resp. 2.000 Kg ha^{-1} each.	Topsoil (0-20cm): D2 (CM 2nd stage) shows the highest C-content during the 2 CR-periods, by mean of the the 3 plots. At the end of the 2nd CR-period (after 14 years) D1, D2 and O2 differed significantly from all other methods. D2 with almost 20% more C-content than K2. In the subsoil the relative difference of D2 to K2 increased by 9% after 2 CR-periods.	Humus ↑
Bohne et al., 1996[SP61]	Field trial; 1992 – 1993; acer pseudoplatanus; random. block, 4 replications; decalcified lessivé from loess over terracegrit	BWC 78,5 Mg ha^{-1}, 300 Mg ha^{-1}, MC_H 53,5 Mg ha^{-1} (f.m.); single application; control without fertilisation	SOM increase solely by means of high compost application (300 Mg f.m. ~ ca. 10 matter% on 20 cm !!!) increase from 1,78 – 1,93 % to 2,75 % (relative increase ca. 50 %).	Humus ↑ (extremely high compost application)
Bragato et al., 1998[SP62]	Field trial, 5 years CR: M, W-W, SB random. Block, 4 Wh. silty loam;	SSC, Slu annually 7,5 and 15 Mg f.m. ha^{-1}; control: min. N-fertilisation	The application of dehydrated Slu and SSC-compost caused an increase in the TOC-content of the soil (from 0,71 to 0,86 %; relative increase 21 %); *not significant*	Humus ↑
Buchgraber, 2000[SP63]	6 fieldtrials, on different sites, 1994 – 1998; M, W-W, W-Bar, S-Bar, Pu, Ra, IC; 1 trial random. block, 6 replications; grassland	BWC 7,5 – 20 Mg ha^{-1}; MC 10-25 Mg ha^{-1}, with M and Ra 54 Kg ha^{-1} min. N - supplement, granulated BWC	SOM increased on arable land by an avarage of 1,1 % (from 3,1 to 4,2 %;), on grassland by 0,9 % (from 6,3 to 7,2 %); equivalent to a relative enrichment by 35 resp. 14 %.	Humus ↑
Businelli et al., 1996[SP64]	Field trial, 6 years, M monoculture; random. block; 4 replications;	MWC, 25 – 30 cm incorporated, 1) 30 and 90 Mg f.m. ha^{-1} and year	Significant, proportional increase of TOC in soil after 6 years, in both fertilisation steps (from 0,76 to ca. 0,9 with 30 Mg and	Humus ↑

Authors	Experimental Design	Fertilisation	Results	Remarks
1996[SP64]	random. block; 4 replications; argillaceous Loam, pH 8,3; Corg 0,76%,	1) 30 and 90 Mg f.m. ha^{-1} and year 2)each 30 Mg ha^{-1} during the 1st and the 4th Jahr min. NPK-supplement 3)control: NPK without compost	in both fertilisation steps (from 0,76 to ca. 0,9 with 30 Mg and almost 1,5 % with 90 Mg/ ha*a) (relative increase with 30 Mg-variation 18 %, with 90 Mg-variation 97 %).	
Delschen, 1999[SP65]	Long-term trial, recultivation after mining, since 1969 resp. 1981 – 1996, Loess	Manure, MWC, Slu, NPK regional standard application	Increase of SOM between 0,02 and 0,08% per year, the increase levels off, with the years. Type of organic fertilizer has less influence than the fertilisation rate. Slight increase of microtoxins, but much below background contamination.	Humus ↑
Diez & Krauss, 1997[SP66]	Field trial, 20 years, 2 sites: CR: SB-W-W - S-Bar sandy loam, CR: Pot - W-W – S-Bar Loess loam; no information to statistics	MWC, year 1 – 12: every 3rd year 40 – 45 Mg d.m. ha^{-1}, year 13 – 20: annually 15 Mg d.m. ha^{-1}, with and without min. NPK-supplement; control: without fertilisation and NPK without compost	At a mean org. matter supply of 4,4 Mg ha^{-1}*year, increase of SOM by 0,4 – 0,5 %-points (equivalent to ca. 17 % relative enrichment) at both sites, without org. fertilisation: 0,5 % decrease (relative decrease 16 – 19 %)	Humus ↑
Hartl & Wenzl, 1997[SP67]; Hartl et al., 1999[SP68] Hartl & Erhart, 2001[SP69]	Field trial „STIKO“ to date 9 years; CR: W-R, Pot, W-W, O, SP, Pot, W-W, W-Bar latin square, 6 replications. calcareous grey alluvial soil, sandy/loamy silt watersoluble organic substance (WOS), NIRS-analytics for N & C.	combined fertilzation: 3 Comp- + 3 min.N-supplementary levels Comp fertilisation total $1992^{-1}996$: BWC 669, 1139 and 1610 Kg N ha^{-1}, in various combinations with mineral fertilisation BWC 1(12,5), BWC 2 (22,5) and BWC 3 (32,5 Mg f.m. ha^{-1} and year),	SOM 1997: BWC 1: 3,51; BWC 2: 3,94 (sign.); BWC 3: 3,99 % (sign.) in comparison to 3,23 % with non-fertilized variation, relative increase 9 % to 24 %. After 4 years of increasing compost application changes in the formation of humic substances: increase of watersoluble organic N as well as watersoluble org. C, and C_{tot} (from 2,31 to 2,95 2,66 % = rel. enrichment max. +28 %) and N_{tot} (from 0,26 to 0,29 and 0,28 %).	Humus ↑
Klaghofer et al., 1990[SP70]	Field trial, 4 years, vineyard, 5 – 8 ° slope, latin square, 4 replications.; shallow, calcareous, high sandcontent, erodible, rainsimulator experiments	control, NPK, BWC 75 Mg ha^{-1}, 150 Mg ha^{-1} (single application, 1983)	SOM in topsoil 1983: 2,0%; 1986: control: 1,7%, NPK:1,6%, MC 75t: 2,0%; MC 150t: 2,2%. increase 0,3 – 0,5%	Humus ↑
Leifeld et al., 1998[SP71]	Field trial, 10 years, lessivé from loess pedological basic parameters, degree of humification of polysaccharides,	MC 60 Mg f.m. ha^{-1}, BWC 60 Mg f.m., NPK, control without fertilisation	2 years after the last fertilisation Corg-increase in comparison to control from 1,17 to 1,4 % (rel. enrichment 32 %), highest C- and N-increase found in the clay fraction, BWC shows stronger effect than MC. Degree of degradation	Humus ↑

Authors	Experimental Design	Fertilisation	Results	Remarks
	lignins and lipids, composition of the C-pools		of polysaccharides and lignin content increased through MC. Organic fertilizers have an effect on the organic matter content, but not on composition.	
Maynard & Hill, 2000[SP72]	Field trial, 3 years, onions, 3 replications. (1994 only 1)	Leafcompost 50 T/A, NPK on both plots	Increase of SOM from 3,4 to 4,3% after 3 years.	Humus ↑
Parkinson et al., 1999[SP73]	Field trial, 3 years, 10-year For-M-monoculture random. block, 3 replications; humic (8,8% OM) silty loam	GWC: 0, 15, 30, 50 Mg f.m. ha^{-1}*a with and without min. NPK-supplementation (125:27:56 Kg ha^{-1})	SOM increases after 3 applications of compost on all Comp plots. *Significant* increase but only from 50 Mg f.m. ha^{-1} (total 150 Mg in 3 years; from 8,9 to > 11% d.m., which corresponds to a relative increase of 24 %).	Humus ↑
Tenholtern, 1997[SP74]	Largeplot facility 3 years, no replications., Kultosol, single application	SMC 0, 20, 40, 80 Mg ha^{-1} moist with and without NPK; 0, 40, 120 and 360 Mg ha^{-1} fresh matter.	SOM in topsoil (0-15 cm): 0: 0,40 %; 40: 0,81%; 120: 0,90%; 360: 2,31%; rel. SOM enrichment of 102% (40); 125% (120) und 478% (360).	Humus ↑
Schwaiger & Wieshofer, 1996[SP75]	Field trial, 1989 – 1996, Longplots, 3 replications. CR: W-W, W-R, W-R calcareous grey alluvial soil; sandy/loamy silt,	BWC: 20, 40, 80 Mg ha^{-1}; MC_H: 20 Mg ha^{-1}; 3x 1989 – 1996; provisional result 1992	Deviation from control in percentage Corg: BWC 20: +6%, BWC 40: +13%, BWC 80: + 44%	Humus ↑
Timmermann et al., 2003[SP76]	Comp-longterm-experiment (8 resp. 5 years): duofactorial splitplot design with 12 variations at 4 replications each, randomized → 48 experimental plots per trial 6 locations : lS, uL, uL, utL, uL, sL CR: Corn – W-W – W-Bar	Comp application: 0; 5; 10; 20 Mg ha^{-1} N-complementary fertilisation level N0: no additional N-aoolication level N1: 50 % of the optimal N-application level N2: 100 % of the optimal N-application on basis of the Nmin-content of the soil as well as further aspects, like precrops etc. (Comp nitrateinformationservice - NID).	Original SOM was increased by compost applications of 5, 10 resp. 20 Mg ha^{-1} d.m., meanvalue at 0,23 %, 0,46 % resp. 0,92 %. Humic substance fractionation: trend towards a clear increase of humic acids and a lesser increase of fulvic acids with increased compost application rates and with it the C-dose, whereas the according fractions are site-specifically different. Accordingly the results show a trend towards a „matured“ organic matter.	Humus ↑
Weissteiner, 2001[SP77]	8-year field trial (1993–1999), CR: Corn-M-So-W-W-W-Bar-FE-WRa- Corn-M- W-W 4 replications loamy silt	BWC/MC some +/– compoststarterbacteria [MC_B], 12,5 – 24 Mg d.m. ha^{-1} (= 21 – 38,4 Mg f.m.) and year, 7 variations; (with and without min.	At an average application of 3 Mg $ha^{-1}y^{-1}$ organic compost matter the SOM increased from 1,9% by ca. 0,3 to 0,4% (relative increase 16 – 21%) within 5 years.	Humus ↑

Authors	Experimental Design	Fertilisation	Results	Remarks
		NPK-supplementation, with and without application of chemical-synthetic fertilizers), standard = customary conventional NPK fertilisation without compost)		
Zinati et al., 2001[SP78]	Field trial since 1996, calcareous soil with 67 % pebblecontent (>2mm); vegetables	BWC (100 %), Bedminster Co-Compost (75% BWC and 25% SSC) and SSC (100%); application 1996 and 1998, 72, 82,7 and 15,5 Mg ha^{-1} d.m., = 168 Kg N ha^{-1}*a; control = 0 and NPK treatment	19 months after application: lowering of pH, rise of conductivity, C_{org}-total content was in BWC, Bedminster CoComp and SSC 4-, 3- and 2-times higher than in control and NPK, BWC increased C_{org}-total content within the gravelfraction 4- (0^{-1}0 cm) resp. 3-fold (10 – 22 cm), more than the other Comp. Corg-enrichment decreased in greater depth in allen variations in soil fraction (<2mm), but not in gravel fraction (>2mm), signicficant increase of Corg-content in humus, humin- und fulvic-acids through BWC	Humus ↑

3.2 Excursus – assessment of compost as carbon sink and its contribution to climate protection

3.2.1 ECCP – European Climate change Programme; European Commission, 2001[FA79])

The European Climate Change Programme (ECCP) was set-up in June 2000, in order to develop the most efficient additional measures to achieve the EU reduction target of the Kyoto Protocol for greenhouse gases of 8% during the first reduction period from 2008 – 2012 (decision of the Council, 2002/358/EC).

Calculations of the European Environmental Agency (EEA) resulted in an amount of 336 Mt CO_2eq to be reduced in order to meet the –8% Kyoto target.

The final report of the *Working Group Agriculture* of the ECCP (2002[FA80]) concludes: *carbon sequestration in agricultural soils has a potential to significantly contribute to climate change mitigation. There is a potential to sequester up to 60-70 Mt CO_2 y^{-1} in agricultural soils of EU-15 during the first commitment period, which is equivalent to 1.5 – 1.7% of the EU's anthropogenic CO_2 emissions. Promising technical measures are linked to reduced soil disturbance and increased input of organic materials to arable fields.*

The most important measures are:

- the promotion of increased carbon input from organic amendments (animal
- manure, compost, crop residues, sewage sludge)
- organic farming
- conservation tillage
- permanent re-vegetation of set-aside areas with perennial grasses
- woody bio-energy crops instead of rotational fallow

In 1990 the CH_4 emissions from agriculture amounted to 41% of the total of CH_4 emissions. The portion of N_2O was 51%. The agricultural portion of the total climate gas emissions (inclusive CO_2) was 11%.

The Bonn (Germany) conference on climate change acknowledged agricultural soils as valid C-sinks. Following from this the DG Environment assumed 20% of the agricultural soils in the EU as potential sinks. This would result in a sorption potential of 7.8 Mt C, corresponding to 8.6% of the total EU reduction target of -8 %. The ECCP report ECCP (2002) designs scenarios of carbon storage in soils under realistically *"feasible"* frame conditions. A potential of 60 to 105 Mt of compostable household wastes is estimated for *composting* (without residues from agro-industries, sewage sludge etc.) that corresponds to 21 – 37 Mt compost y^{-1}, (i.e. 13-22 Mt y^{-1} d.m.). At an average application rate of 10 Mg d.m. ha^{-1} y^{-1} this results in a farmland demand of 1.3 – 2.2 million hectare. From this deduced was a realistic, medium-termed storage potential of 11 Mt CO_2 y^{-1}. Related to 1 ha this represents a contribution of 1.38 Mg CO_2 ha^{-1} y^{-1} at an estimated error of +/-50%.

TABLE 3-5: ASSESSMENT OF CARBON SEQUESTTRATION BY COMPOSTING AND COMPOST APPLICATION ON SOILS (ECCP, 2002)

Measure	**Sequestration Potential per unit area** [Mg CO_2 $ha^{-1}a^{-1}$]	**Potential in EU-15 during first commitment period1** [Mt CO_2 a^1]	**Environmental side effects**	**Impact on farm income**
Promote organic input on arable land (crop residues, cover crops, farm yard manure, compost, sewage sludge)	1-3	20	Chemical fertiliser can be partly replaced, leading to reduced N_2O emission and reduced nitrate leaching. Accounting of additional nitrogen input is required to avoid nitrogen overdose and nitrate losses. Erosion control and reduced nitrate leaching under cover crops. Danger of contamination by heavy metals and other pollutants, as well as bio-safety issues, are controlled under Community and national legislation. Reduced pathogen risk from composted material.	Positive long-term tendency due to better soil fertility. Easy implementation, but potentially higher costs due to transport and purchase of organic material and compost production On-farm composting can provide an additional source of income. Capital and operational costs incurred by setting up a composting facility at farm level may be offset by (1) a fee for taking organic waste (2) income from selling compost (3) savings in fertiliser, water consumption, disease suppression.

3.2.2 Further considerations – for a comprehensive evaluation of beneficial effects contributing to the mitigation of green house gases

According to Hogg et al. (2002[FA81]) for the possible savings of climate gases especially in regard of eco-balances the following must be considered:

- carbon sink of the SOM and the applied compost which is incorporated in the SOM polls
- the improved supply of plant nutrients by the application of compost
- the reduced energy consumption equivalent to the saved mineral fertiliser (substitution effect)
- Reduction of nitrous oxide emissions (N_2O) by the reduction of available N-surplus from easily soluble N-sources (e.g. mineral fertiliser)

But secondary effects which can be quantified only in the long run should be also included in order to obtain a comprehensive picture of the ecological performance of compost utilisation.

- Reduction of pathogenic pressure in agricultural crops (hereby reduction of the energy demand for production and application of pesticides).
- Better resilience of soils against erosion (here it must be questioned in which way soil losses would have to be assessed in the frame work of life cycle analyses).
- Improved workability of the soil (lower energy demand for ploughing, tilling etc.)

Peat substitute and the substitute of farm fertilisers are also ranking among the climate relevant functions of compost according to Grontmij (2005[FA82]). Assuming a C-content of about 50%, 1 m^3 peat with a bulk density of ca. 300 Kg m^{-3} contains approx. 150 Kg C. At a 90% mineralisation of peat after decomposition 222 Kg CO^2 for each m^3 peat could be saved which would be substituted by compost.

Grontmij (2005) assessed the $CO_{2\ Äqu}$ –balances of composting of organic waste (VFG = *Vegetable Fruit and Garden Waste*) and of compost application. Without consideration of peat substitution (-40,2 Kg $CO_{2\ Äqu}$ Mg^{-1}) and for two scenarios for the substitution of mineral fertilisers the authors computed an emission reduction between -26.2 and -54.7 Kg CO_2 equ Mg^{-1} of organic waste. Assuming a 40% compost output this corresponds to saving of approx. -66 to -137 Kg CO_2 equ Mg^{-1} compost (details see Table 3-6).

TABLE 3-6: CO_2 EQU –BALANCE OF COMPOSTING ORGANIC WASTES (VFG = VEGETABLE, FRUIT AND GARDEN WASTE) AND COMPOST APPLICATION (GRONTMIJ, 2005)

	Net Emission [Kg CO_2 equ Mg^{-1} organic waste]
1. Energy consumption of composting	+ 17,4
2. Emission climate gases (predominantly N_2O, CH_4)	+ 35,4
3. Compost functions	
3a. Substitution of peat	[-40,2; not calculated]
3b. Substitution mineral fertilisers low (high)	– 28,7 (– 57,2)
3c. Substitution of farm fertilisers	0
3d. Carbon sink in the soil	– 24,2
4. Reduced N_2O emissions compared with mineral fertilising	– 22,9
5. Disposal of residues from composting (MBT/incineration-mix)	– 3,2
Total	**– 26,2 (– 54,7)**
Total [Kg CO_2 equ Mg^{-1} Compost]	**– 66 (– 137)**

The authors point out that the additional positive effects (i) resistance against plant pathogens, (ii) yield, (iii) long-term increase of soil fertility (soil functions) must be included in future and the corresponding calculation models developed.

Allocated on 1 ha arable land the savings would result in 1.066 Kg to 2.192 Kg CO_2 equ ha^{-1} y^{-1}at an application of 16 Mg f.m. ha^{-1} y^{-1}.

Schubert et al. (2004[FA83]) assessed a reduction potential of greenhouse gases between 13.5 and 22% comparing pure incineration respectively MBT options and separate collection with subsequent compost use on a basis of fertiliser equivalents.

Related to the land area the authors calculated a reduction potential for the exclusive compost scenario (without anaerobic pre-treatment) between 6700 Kg und 8500 Kg CO_2 equ ha^{-1} y^{-1}.

Depending on the assumptions made respectively the chosen reference scenario the figures show a considerable variability. But all studies and models come to the result that separate collection, composting and compost utilisation in agriculture are leading to remarkable reductions of greenhouse gas emissions. This claims for a Europe-wide acknowledgment for crediting emission certificates on C-sinks created by composting and compost use.

3.3 *Effect of compost fertilisation on yield*

3.3.1 Basic conditions to estimate yield effects of compost fertilisation

Most of the evaluated literature is dealing with yield effects. The contribution of compost application to biomass production is an essential success indicator from an agronomic and operational perspective. The cost-benefit view would ask: Does the “time involved” in compost fertilisation pay off considering achieved yields?

Here it is necessary to distinguish between a short-term “annual effect” and the long-term “soil improving effect” which indirectly would enhance soil productivity factors in time. The latter cannot be necessarily measured in direct success rates like any other long-term investment and needs an anticipating thinking of business or rather soil management in the sense of a sustainable economy.

Three types of experimental designs can be distinguished which

1. apply compost in practice relevant quantities - also regarding nutrient supply (on an average up to approximately 10 Mg d.m. $ha^{-1}y^{-1}$)
2. apply quantities above average on account of experimental efficiency in the frame of the test design (e.g. 20 Mg d.m. $ha^{-1}y^{-1}$ and more)
3. examine a long-term effects of repeated compost applications or a one-time applications of large quantities aiming for specific soil amelioration

Furthermore a wide range of local site conditions (soil and climate) and land use must be taken into account for in depths interpretation of the results. E.g. the latter are

- crop rotation
- time of application
- application technique (incorporation, mulching)
- combination with other fertilising measures
- compost quality and type (C/N ratio, nutrient level, type of initial materials – sewage sludge, green cuttings, manure compost etc.)

These parameters are strongly varying and systematic information is often missing.

This high variation of operational and site factors and the specific combination of each do exclude an assessment in which causal relations to individual factors (e.g. a definite nutrient load; compost characteristics) can be allocated.

The effect of compost fertilisation on yield has been researched in both potting tests (see Table 3-11) and field trials (see Table 3-10). A transfer of findings from pot tests to field conditions is limited. The typical compost portions realised in pot experiments under lab or greenhouse conditions a well suited for testing substrates in ornamental and intensive horticulture. However, pot trials under controlled experimental conditions help a lot in researching principle impacts and behaviour patterns of compost amended cultivation systems.

Besides nitrogen the nutrients phosphorus, potassium and magnesium play an important role for plant nutrition. In this context some questions are asked for the agricultural praxis:

- What is the concentration of nutrients in compost?
- How is the plant availability of these nutrients?

- Does compost increase the yield?
- Does compost influence the quality of plants?
- Is compost a competitive fertiliser (in the sense of a cost-benefit analysis respectively fertilising efficiency?

3.3.2 Examples of experimental results

There are a lot of different studies especially about the effect of compost on yield. These studies often differ in methods and tasks but nevertheless it is possible to make some conclusions.

The most studies showed a positive effect on compost on yield. This is valid in comparison with unfertilised control plots and in some cases also against treatments with mineral fertilisation.

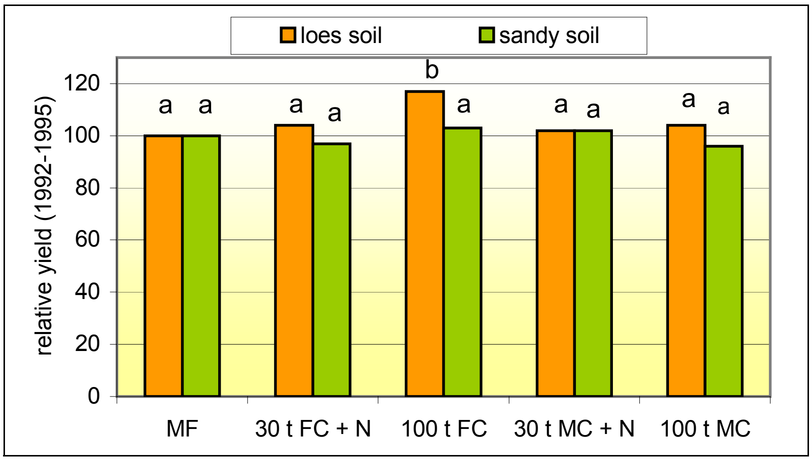


FIGURE 3-7: RELATIVE YIELD OVER 4 YEARS (1992–1995) MF ... MINERAL FERTILISER, FC…FRESH COMPOST; MC… MATURE COMPOST (PETERSEN & STÖPPLER-ZIMMER, 1996)

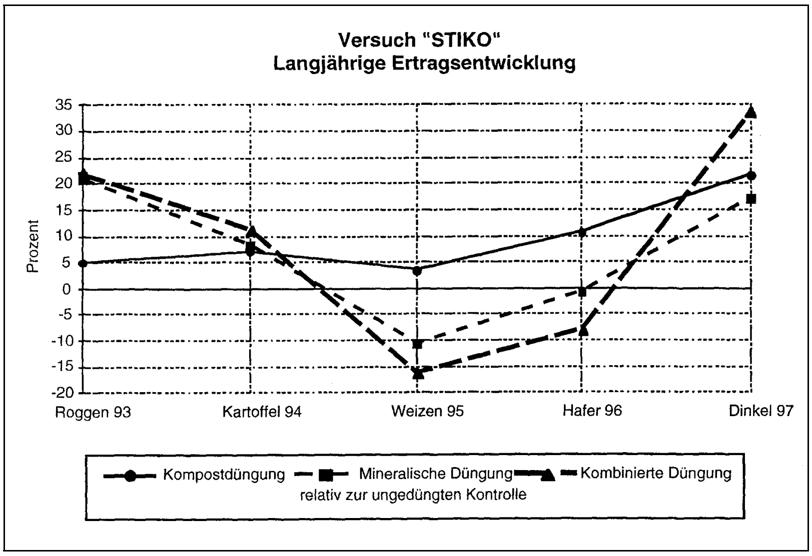


FIGURE 3-7: YIELD DEVELOPMENT WITH COMPOST AND MINERAL FERTILISATION SYSTEMS (HARTL & ERHART, 1998[SP84])

Petersen & Stöppler-Zimmer (1996) compared the effect of different types of compost (fresh and finished compost) and different amounts of applied compost on two soils with mineral fertilisation. On a sandy soil they could not found any difference in yield between mineral fertilisation and compost fertilisation within a four year period, whereas on a loess soil application of 100 Mg ha^{-1} (= 25 Mg $ha^{-1}y^{-1}$) of fresh compost indicated a significant higher yield in comparison to mineral fertilisation (Figure 1-1). Fresh compost supplies a slightly higher level of available nutrients (N-P-K)

Hartl & Erhart, 1998[SP85]) ascertained in a long-term trial that by fertilisation with biowaste compost higher yield safety is achieved than with mineral fertilisation. An undersupply of nutrients was measured during the initial years (see Figure 3-7). After the first too years the compost led to an equal nitrogen supply. Contrary to the initial fears of an uncontrolled nitrogen mineralisation as compared to mineral fertilisation compost did not lead to an over nutrition of plants. An supplementary N fertilisation in compost plots must be considered with caution and a good adjustment with crop rotation is decisive.

Klasnik & Steffens (1995) investigated the effect of compost at different application rates and levels of nitrogen supplementation in comparison to a recommended PK control. In the treatments with no nitrogen mineral fertilisation the yield increased from 1.5 to 2.5 Mg ha^{-1} with increasing rates of compost. This increase in yield can be attributed to the effect of nitrogen. But even at the highest rate of compost (120 m^3 $ha^{-1}y^{-1}$) the effect of compost nitrogen is much less than 100 Kg ha^{-1} mineral N-fertiliser which increased the yield from 1.5 to 3.4 Mg ha^{-1}. They also proved that compost could influence the plants quality.

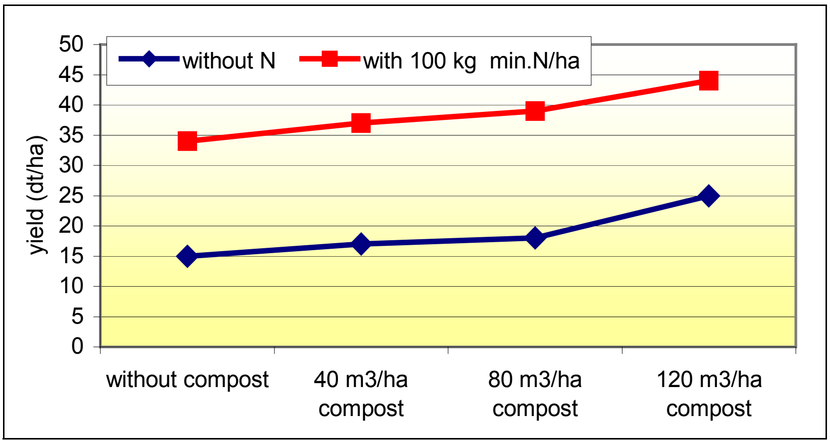


FIGURE 3-8: INFLUENCE OF COMPOST WITH AND WITHOUT SUPPLEMENTARY MINERAL N FERTILISATION ON YIELD OF TRITICALE (KLASNIK & STEFFENS, 1995)

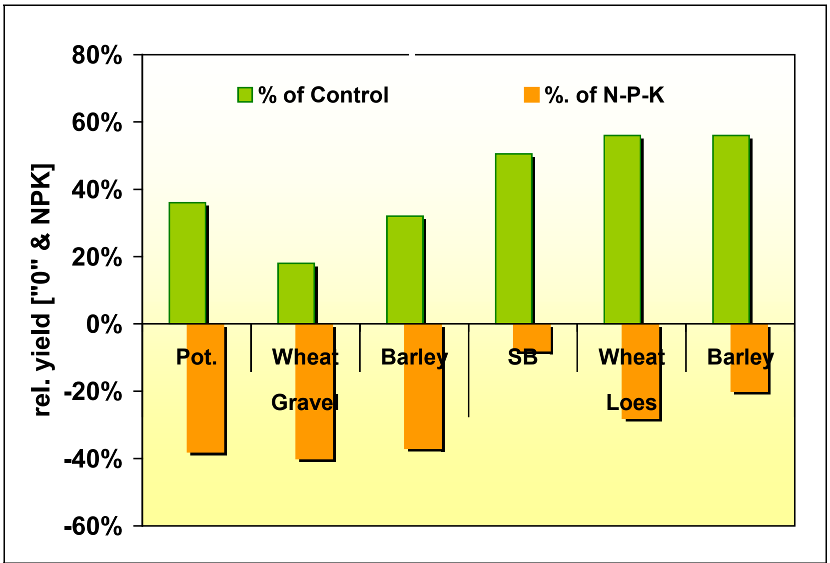
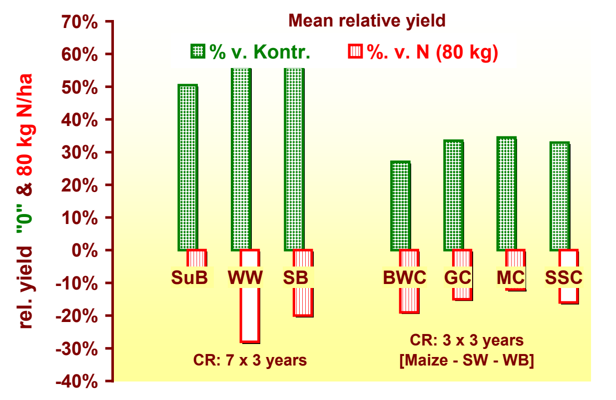


FIGURE 3-9: EFFECT OF COMPOST ON YIELD IN COMPARISON TO AN UNFERTILISED CONTROL AND A RECOMMENDED NPK CONTROL (POT: POTATO, BARLEY: SPRING BARLEY, SB: SUGAR BEET (DIEZ & KRAUSS, 1997)

Application of compost could increase the amount of crude protein from 10.6% up to 13.2% at different compost rates.

Hartl et. al. (1998) also found positive changes in plant quality with an increasing amount of gluten in wheat after compost treatment. Warman & Harvard (1997) investigated the influence of compost on quality characteristics too, but they found no difference in the amount of vitamins in carrots and cabbage between conventional and compost fertilisation.

Diez & Krauss (1997) compared the effect of compost on yield with an unfertilised control and a recommended NPK control in a long term investigation (Fig. 3). Compost application at a rate of 20 Mg ha^{-1}/y could increase the yield in comparison to the unfertilised control between 20 and 60 % but could not reach the yield of the mineral fertilised control. On the loess soil the effect of compost application is much better than on the “gravel” soil. Similar results were reported by Buchgraber (2001), Reider et al. (2000) and in a study of HDRA Consultants (1999). These results let suppose that compost could not be compared with mineral fertilisers because of the different dynamic of fixation for nutrients.



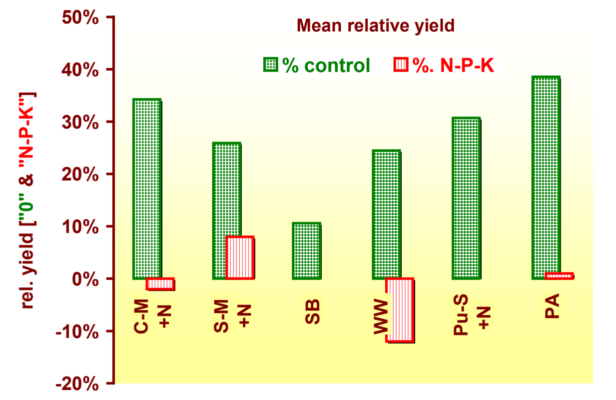


FIGURE 3-10: MEAN RELATIVE YIELD OF COMPOST PLOTS COMPARED TO CONTROL AND MINERAL FERTILISER PLOTS (80 KG HA^{-1}); SUB ... SUGAR BEET; WW...WINTER WHEAT; SB...SPRING BARLEY; SW…SPRING WHEAT; WB…WINTER BARLEY; BWC...BIOWASTE COMPOST; GC...GREEN COMPOST; MC...MANURE COMPOST; SSC...SEWAGE SLUDGE COMPOST (AICHBERGER ET AL., 2000)

FIGURE 3-11: MEAN RELATIVE YIELD OF COMPOST PLOTS (ALSO WITH SUPPLIMENTARY MINERAL N ADDITIONS) COMPARED TO CONTROL AND MINERAL FERTILISER PLOTS (N-P-K); C-M...CORM MAIZE; S-M...SILAGE MAIZE; SB...SPRING BARLEY; WW...WINTER WHEAT; PU-S...PUMPKIN SEEDS; PA...PASTURE (BUCHGRABER, 2002)

3.3.3 Economic assessment and competitive ability of compost

The represented studies mostly did not investigate the question about competitive ability of compost because only in a few of them an economical consideration was made.

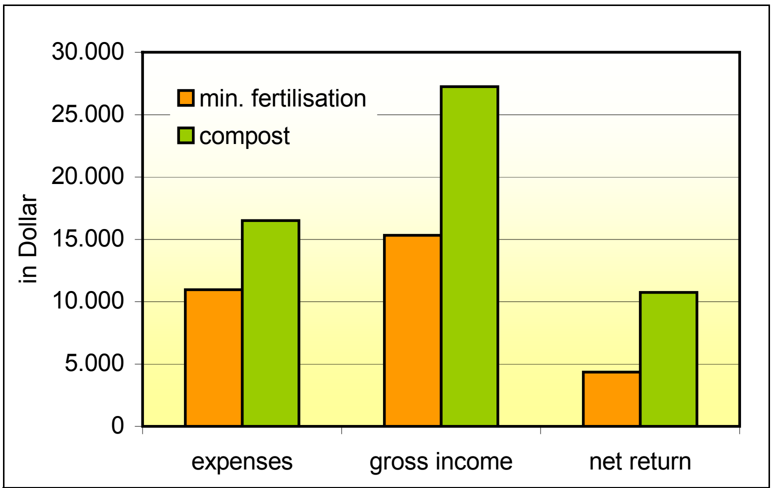


FIGURE 3-12: EXPENSES, GROSS INCOME AND NET RETURN OF A TOMATO PLANTATION WITH AND WITHOUT COMPOST FERTILISATION (STEFFEN ET AL.,1994)

Steffen et. al. (1994[FA86]) Steffen et. al. (1994) compared the expenses, the gross income and the net return of a tomato plantation with compost fertilisation and mineral fertilisation. The expenses for the compost fertilisation were substantially higher compared with mineral fertilisation but the additional expenses were more than compensated by the profit as an result of higher yield and better quality after compost application (Figure 3-12).

HDRA Consultants (1999) got other results. They calculated for the different compost treatments in every case a worse net return in comparison to mineral fertilisation. The net return was partially negative because of high expenses for compost application and a missing higher yield.

TABLE 3-7: NET RETURN (DEFICIT) IN £ AT DIFFERENT TREATMENTS (HDRA CONSULTANTS, 1999[FA87])

	winter wheat	winter barley	rape (oil seed)
NPK	952	201	276
39 Mg compost + NPK	635	-42	89
117 Mg compost + P	-241	-424	$^{-1}$19
117 Mg compost + NK-reduced	16	-352	$^{-1}$55

The following figure from the brochure *Organic Fertilisation* (BGK e.V., 2005) summarizes the economical assessment of compost utilisation as follows:

The monetary value of organic fertilisers results from

- the contents of plant nutrients and alkaline effective material (lime)
- the content of organic matter

The value of mineral fertiliser equivalence is calculated from the chargeable content of nitrogen necessary for fertilising and the total content of phosphate, potassium, magnesium and lime.

TABLE 3-8: VALUE OF NUTRIENTS (RANGES DUE TO NUTRIENT CONTENT AND DRY MATTER)

Organic fertiliser	Nutrients (N, P, K, CaO) € Mg^{-1} f.m. [(1)]	€ ha^{-1} [(2)]
compost	5,80	230
digestate, liquid	4,50	140

1) Equivalent costs for mineral fertilisers. N 0.60 € Kg^{-1}; P_2O_5 0.51 € Kg^{-1}; K_2O 0.26 € Kg^{-1}; CaO 0.03 € Kg^{-1}; magnesium, sulphur, trace elements and organic matter are not included. *[Chamber for agriculture Hannover & Weser-Ems]*. Prices for mineral fertilisers *in € Kg^{-1} nutrient.*

2) Value per ha at medium nutrient and dry matter contents. Application rates: Compost – 40 Mg $3y^{-1}$, digestate liquid – 35 m³ ha^{-1}.

The economical value of organic matter is much more complex. It proves e.g. in the stabilisation and increase of revenues per hectare, which result from the enhanced soil fertility due to proper humus management and the easier cultivation of the land. Compared with other organic fertilisers compost shows here its actual strength. The benefit becomes effective in the long run.

TABLE 3-9: INCREASE OF SPECIFIC INCOME IN CASH CROP FARMS WITH ENHANCED HUMUS MANAGEMENT (FROM BGK E.V., 2005; DIMENSION: € HA^{-1}; LUFA AUGUSTENBERG, 2003[FA88]; SCHREIBER, 2005[FA89])

€ ha^{-1}	year 1	year 2	year 3	year 4	year 5	year 6	year 7
15 Mg d.m. compost $ha^{-1}3a^{-1}$	38	48	52	53	54	55	55
30 Mg d.m. compost $ha^{-1}3a^{-1}$	53	78	90	97	102	106	108

Economic comparison on farm level, all relevant cost factors are considered; compost delivered to the field.

According to calculations of the FAO the world-wide phosphate stocks last for approximately 90 years. Stocks for the actually used phosphate poor in potassium are retreating distinctly faster. Therefore the closing of phosphate loops is not only important for the protection of the soil but also on account of a safe and long-term maintenance of agriculture. Plant nutrients are absolutely limiting food production. Consequently prices for phosphate will increase in a short term.

3.3.4 Summary – yield effect of compost fertilisation

The application of compost stabilises and increases the yield potential together with qualitative attributes of crop products. The results depend very much on the yield potential of the location and crop rotation. Cultures with a longer vegetation time have an improved utilisation of compost use. Compost can be seen as an organic multi-nutrient fertiliser and substitutes, besides the predominantly soil improving (humus, alkaline effective components) components a phosphor and potassium fertilisation.

The yield effect is usually realised in medium-scale at a regular compost application during the 2nd and 3rd period of crop rotation, i.e. after approximately 3 to 6 years. Short-term tests (of up to 3 years) may not be recpommended for a valid and robust interpretation. (Ebertseder 1997[SP90], Gutser 1999[SP91], Buchgraber 2002[SP92], all in Timmermann et al., 2003[SP93]).

Few experiments do not verify an influence on yield, but on quality parameters (e.g. oil pumpkin, potatoes, green land, vegetables).

Long-term field trials proved the equalising effects of compost of annual/seasonal fluctuations. Thus a higher yield safety can be expected than with a pure mineral fertilisation.

Some tests showed best results with combined compost and mineral N-fertilisation. Better results could often be achieved if during the first years higher compost quantities were applied every 2 to 3 years contrary to the annual fertilisation with lower quantities (< 10 Mg d.m.).

The literature as well as the expert discussions during the symposium confirmed that compost cannot be assessed exclusively on account of the short-term fertilisation effect. Compost provides nutrients in different bonding and mobility forms. It changes the soil conservation and formation processes and the exchange dynamics for nutrients as well as the water household and material transformation. This stands in close connection with the properties of the humified organic matter i.e. the colloidal structure of humic matter. In this context the importance of amino acids and amino sugars in humic matter and aggregate formation has to be reflected (Scheller et al., 1997[FA94])..

From this a more comprehensive and long-term system approach is necessary in assessing compost than for mineral, purely nutrient-related fertilisation.

3.3.5 Yield effect of compost fertilisation – tabular survey

TABLE 3-10: YIELD EFFECT IN FIELD TRIALS – TABULAR SURVEY

Authors	**Experimental Design**	**Fertilisation**	**Results**
Effect on yield – <u>Field trials</u>			
Aichberger et al., 2000[SP95]	Field trial 1991 – 1999; loamy silt CR: Corn-M-SW-W-Bar; random. Block, 4 Wh	BWC, GWC,MC_C, SSC; basis: 95 resp. 175 Kg N ha^{-1}; + 80 Kg N ha^{-1} from NAC (Nitramoncal) with Corn-M, 60 Kg with cereals, 0-40-80^{-1}20 Kg N ha^{-1} mineral (NAC), standard = 80 Kg N ha^{-1}	Average yield reduction compared to control by mean of all Comp, crops and trial years: $^{-1}$5,5 % (equivalent to ca. 40 Kg mineral-N-equivalents). Best effect on yield through MC_C, GWC 3 % less, SSC 4 % less, BWC 7 % less.
Amlinger & Walter, 1993[SP96]	longplots, 3 replications. CR: W-W, W-R calcareous alluvial soil; sandy/loamy silt,	BWC:, 40, 80; MKP: 20 Mg ha^{-1}; 3x 1989 – 1996; provisional results 1992	1st year, W-W→ 0: 1750 Kg; BWC/20t: 1880 Kg; BWC/80t: 2760 Kg (+39,5% > ‚0‘); BWC/40: 2450 Kg (+27,8% > ‚0‘, *p<5%*); generally low yield 2nd year, W-R → > 4000 Kg; BWC/40t and BWC/80t +10% rel. to ‚0‘; 3rd year, W-R → BWC40 Mg +26 %, 80 Mg +31% from ‚0‘ (*sign. p<5%*)
Amlinger et al., 2000[SP97]	Preliminary trial skislope recultivation 1800 m sea-level, slate, brown loam, alpine pasture (maintenance fertilisation) talus (recultivation); effect on yield, feed quality, phytosoziology, soil-physics	BWC resp. GWC w/manure, 1998:(20, 40, 80 Mg f.m. ha^{-1} resp. 15, 30, 60 Mg f.m. ha^{-1} on pasture), 0, Biosol	No statistical evaluation, but distinct increase of yield with Comp application compared to control and Biosol variations on all soils; distinct increase of legume fraction in comparison to grasses.
Asche et al,. 1994[SP98]	2-year field trial 7 sites on loess-lessivé; CR: SB - W-W	7 different BWC, non finished & mature Comp; BWC: 30 Mg d.m. ha^{-1} each plot min. N: according N_{min}-method BWC_{raw} & BAK_{mature}+min.N accord. N_{min}-method	1st year, SB → no significant effect on yield → possible influence might be superimposed by the good 'fertility' of the experimental sites; 2nd year, → W-W: significant increase in grain yield compared to control, by mean of 7 sites (p ≤ 5%) only with BWC_{fresh}
Baldwin & Shelton, 1999[SP99]	2 years, *Nicotiana tabacum* 1994 & 1995; claysoil → soil- and leafsamples with and without lime application 3 times / year	MWC, SSC and MWSC 2 years; Comp application only 1994: 0, 25, 50 and 100 Mg TM ha^{-1}; 0 and 4000 Kg lime resp. pH 5,8 & 6,5; 224 Kg N, 56 Kg P; 1995: only lime, N and P	1st year (1994) → + liming: MWSC ∅ of all treatments:–21% of control (attention: high salinity of comp (!), 50% loss (necrosis) 1st year (1994) → – liming: SSC ∅ of all treatments: +16% of control 2nd year (1995) → no differences; lower yield because of *Peronospora tabacina*
Boguslawsky & Lieres,	Long-term experiment 42 years; deep lessivé on loess;	St 6t ha^{-1}; Comp 25 Mg ha^{-1}; f.m. 20 Mg ha^{-1}; StoM 30 Mg ha^{-1}; DBM 25 Mg ha^{-1}; sheepfold 17	SB mean value: clear effect of org. fertilizer on N_0-site, declining with increased N-level. Positive influence on W-yield through St-

Authors	Experimental Design	Fertilisation	Results
Effect on yield – Field trials			
1997[SP100]	SB – SW - O	hours; combination with ‚0'- and 3 N-level (N_0, N_1, N_2, N_3) org. fertilisation every 3 years with SB	application. During 2nd year positive effect of Comp on O, and - like W – positive reation to StabM. No absolute figures, no statistical information.
Bohne et al., 1996[SP101]	Decalcified lessivé from loess, Acer pseudo platanus (two-year trial)	BWC1: 75,8 Mg f.m. ha^{-1}; BWC2: 300 Mg ha^{-1}, StabM (horse, 9 months stockpiled) 53,5 Mg ha^{-1} single application	f.m. of young shoots → strongest growth BWC2 (+ 51%); BWC1 and control good growth as well; only StabM statistically significant *(*clearly lower*, –17%;p = 0,05)* figures on young shoots in g f.m./plant
Buchgraber, 2000[SP102]	6 field trial, on various sites, 1994 – 1998; M, W-W, W-Bar, S-Bar, Pu, Ra, IC; 1 trial random. block, 6 replications; pasture	BWC 7,5 – 20 Mg ha^{-1}; MC 10-25 Mg ha^{-1}, with M and Ra 54 Kg ha^{-1} min. N–supplementation , granulated BWC	M → dry grain yield: BWC+54N: 114,1 dt ha^{-1}; +25 % of control (stat. sign.), reference sites no differences; higher energy content with BWC and MC. Sil-M → BWC and MC+54N: 177,0 dt resp. 174,6 dt ha^{-1}, +20 % *significant* on control. Quality yield BWC 104 % compared to other variantions, 20 % higher than control. S-Bar and W-Bar → 43,9 resp. 40,5 dt ha^{-1}, same as NPK, but less lodging. W-W → ca. 52,4 dt ha^{-1}, –12 % of NPK., control –30 % of NPK. Ra → 30 dt ha^{-1} inspite of haildamage, BWC –10%, control –20 % of NPK. Ra-grain yield with BWC 7% below NPK, rapeoil yield with BWC 5% above NPK. Pu → Pu-seedoil: BWC +12 % of NPK, +17 % of MC +200 Kg ha^{-1} mineral fertiliser (NPK): +38 % of control. IC/ÖR → NPK: 886 Kg d.m. ha^{-1}, BWC: 44 – 76 %, control 20%. ley → ‚0': 1000 Kg d.m. ha^{-1}, NPK 1400 Kg ha^{-1}, Comp variation –20 to 25% of NPK. pasture → P-K (3 cuts) 54,9 dt d.m. ha^{-1}, BWC 55,7 dt d.m. ha^{-1} StabM: 61,7 dt ha^{-1}, control –25% of BWC.
Businelli et al., 1996[SP103]	Field trial, 6 years, M monoculture; random. block; 4 replications; argillaceous loam, pH 8,3; Corg 0,76%,	MWC, 25 – 30 cm incorporated, 1) 30 and 90 Mg f.m. ha^{-1} and year 2) 30 Mg ha^{-1} during 1. and 4. year min. NPK-supplementation, each 3)control: NPK without Comp	During 3rd and 6th year yield of 90t/year variation similar to NPK-plot, during 6th year the 30 Mg/year variation as well.
Fauci et al., 1999[SP104]	Comp quality with different feedstocks; W-W	10 different SSC and MC with variing additions of ash (0 + 11% v/v), shredded wood and St (44, 50, 67, 75 % v/v)	W-W → Comp plots in spring more robust and darker, yield: 5,1 Mg ha^{-1} on control, 5,8 Mg ha^{-1} on Comp plots, no statistical difference between the different Comp (SSC & MC), tendency towards higher

Authors	Experimental Design	Fertilisation	Results
Effect on yield – <u>Field trials</u>			
		ca. *70 Mg TM* Comp ha^{-1}	yield on W-W with lower chaff content. <u>Note</u>: single high application rate of 70 Mg d.m. ha^{-1}
Gagnon et al., 1997[SP105]	Two-year field trial on 2 soils (clay + sandy loam) SW	$RotM_C$, MC_C, Peat/MC (CC1), Peat/Shrimp-waste-Comp (CC2): application on N-equivalent basis: 0, 90,180, 360 Kg N ha^{-1}; min. N-fertilisation (0, 45, 90, 180 Kg ha^{-1}) Comp (90 Kg N) +. min. N-supplementation	Differing results during two trial years. Linear increase of yield and N-uptake with increasing Comp application (CC1). During first year clearly lower yield on Comp plots compared to min. N. By means of min. supplementation surplus yield of 100 – 1500 Kg ha^{-1} ($p<0,05$). Highest Comp applications (corresp. 360 Kg N ha^{-1}) and min. N fertilisation (180 Kg) caused partial lodging of SW.
Gent et al., 1998[SP106]	SMC and StMu with and without fumigant in potatoproduction	SMC (from horsemanure) 15 Mt ha^{-1}, StMu, SMC + StMu, 0	Vegetative growth stimulated through SMC, no increase in yield. Synergetic effect between Comp application and St-mulch on plant nutrition only on non-fumigated soils. Figures on yield in Kg/m²
Hartl, 1996[SP107]	Field trial, amount of comp and frequency permanent R crop 1992 – 1997 calcareous grey alluvial soil; sandy/loamy silt	BWC; ‚0‘; annually 20 Mg; 2-annually 40 Mg; 2x60 bzw. 70 Mg; 1x 60 bzw. 70 Mg f.m. ha^{-1} in 6 years no information to statistics	Higher Comp applications in fall (40 or 60 Mg f.m. ha^{-1}) resulted in increase in yield during the 2nd and 3rd subsequent year. Low annual Comp applications (20t f.m. ha^{-1}) produced no difference to control.
Hartl & Erhart, 1998[SP108] Hartl et al., 1999 a[SP109]	STIKO-trial since 1992; CR: W-R, Pot, W-W, O, Sp calcareous grey alluvial soil; sandy/loamy silt	BWC 12,5, 22,5 and 32,5 Mg f.m. ha^{-1} and year, NPK according to crop/fertilisation recommendation, combined fertilisation Comp+min.N-supplementation	Starting with the 3rd trial year highest yield with Comp variations. Halmlänge (H) bei 32,5 Mg f.m. Kompost entsprechend 30 Kg mineralischer N-Düngung Keine konkreten Ertragsangaben
Erhart et al., 1999 a[SP110] Erhart & Hartl, 2000	2-year field trial; compost mulch; Apple production (Games Grieve) Sandy, silty loam	BWC-mulch: 28 Mg d.m. ha^{-1} within the row (1); 56 Mg d.m. ha^{-1} within the row (2); 56 Mg d.m. ha^{-1} spread (3); control without fertlisation (0) BWC: 1,06% N; 0,78% K_2O; 0,64% P_2O_5; 21,8% OM; 11,9 C/N.	<u>Increment of trunk circumfrence</u>: increased at 56 Mg row-mulch application in comparison to control ($p=0,05$) <u>apple yield</u>: <u>1st year</u> no significant differences; <u>2nd year</u>: row-mulch (1) and (2) sign. ($p=0,05$) > (0); positive correlation between $N_{hotwatersoluble}$ in soil and apple yield ($r=0,76$); sign. higher number of flower clusters in (2) compared to control.
HDRA Consultants, 1999[SP111]	HDRA-Research Grounds:, ecolog. cultivation, CR: Pot-onion-Ca-carrot-grass/clover	3 different GWC, Basis: 250 Kg N ha^{-1}, x2 and x3, f.m., poultry manure, Slu	<u>Pot 1997</u> → No significant differences in yield between the different treatments, but highest yield with LM_U, lowest yield on the plots without organic fertilisation.

Authors	Experimental Design	Fertilisation	Results
Effect on yield – Field trials			
	sandy loam		Onion 1998 → lowest yield with no fertilisation, slight increase with low and medium Comp application rates, statistically not significant.
HDRA Consultants, 1999[SP112]	Shepton Farms Ltd.; 7 sites; loam, clay and limestone; ecolog. cultivation, various CRs; one year trial	GWC 30 Mg ha^{-1} (=250 Kg N ha^{-1}) one year trial	Yield recorded with Pot, swedish clover and FB: variing results: postivie effect on Pot, in all other cases no or negative effect.
HDRA Consultants, 1999[SP113]	Staple Farm, loam, difficult to cultivate, convential cultivation; CR: W-W – W-Bar – Ra ; four year trial, SOM: 3,5 – 6 %	GWC, 4 variantions: no Comp + customary fertilisation; little Comp (302 Kg N ha^{-1}) + small NPK application; much Comp (605 Kg N ha^{-1}); much Comp (605 Kg N ha^{-1}) + small NPK applic.;	W-W und W-Bar (1996, 1997) → lowest yields on plots without NPK, statistically not confirmed. Acceptable yield with combined fertilisation and only NPK. Ra 1998: slight differences in yield between variations.
Hein, 2000[SP114]	Sandy silt CR: Sil-M – S-Bar with ley undersowing – ley – Pot – S-R. 6 years	MC, RotM, Slu, NPK, PK per 2 LU-equivalent ha^{-1}.	Sil-M and S-Bar with ley → NPK>Slu>RotM>MC. KG → varying for during the years 1993-98. highest yield 93: Slu, 94, 95, 97 and 98: MC, 96: RotM. Pot → NPK>Slu, then RotM and MC. Starch%: MC, RotM>Slu>NPK. S-R → Slu>RotM, MC. NPK causes high storage losses with grains. Only slight differences between MC and RotM fertilisation. With ley best results on MC.
Klasnik & Steffens, 1996[SP115]	Field trial, 3 years, low humus- and -nutrient podzol, CR: W-R, M, Pot.	GWC 0, 30, 60 m^3 ha^{-1}; min. N-fertilisation 0, 30, 60, 90, 120, 150 Kg N ha^{-1}	Minor effect on yield, with M lower yield with sole Comp application, $0^{-1}5$ % mineralfertilisation equivalent , (temporary N-immobilization)
Kluge et al., 1997[SP116]	Field trial since 1995, 1995 M, 1996 W-W	BWC and GWC → 0, 50, 100, 200 % and N-fertilisation → 0, 50, 100 % of „good agricultural practice " (GAP), almost 10 Mg d.m. Comp ha^{-1} on the „optimalvariation"	No significant effect of Comp during initial year, during 2nd year significant increase in yield on the Comp plots ($Comp_{100\%}$ & $Comp_{200\%}$) of 250 resp. 320 Kg ha^{-1} d.m. with W-W. $Comp_{100\%}$; with min. N-supplementation effect on yield lower → balanced N-, and P-balance with $Comp_{100\%}$
Lindner, 1995[SP117]	Field trial since 1994, sandy loam, kohlrabi, leeks	400 dt ha^{-1} finished Comp per year	Kohlrabi and leek no statisctically verifyable differences in yield
MacLeod et al.,	Field trial, 7 sites, randomized	BWC with or without one-way diapers, application	Bar: no significant change on 4 sites, on 3 sites reduction in yield, one

Authors	Experimental Design	Fertilisation	Results
Effect on yield – Field trials			
2000[SP118]	block, 4 replications., CR: Bar – red clover, Pot; fine sandy loam	before Bar, 15 Mg ha^{-1} d.m.	of them with diaper-Comp (because of manganese toxicity); increased P, Na, Cu and Zn-values in plant tissue of the Comp fertilized plants in comparison to control, P, K, Ca and Mg-values in diaper-Comp variation higher. Average leaf yield in mean of all sites 25% higher than on Comp variation. Increase in all macronutrients N, P, K, in the leaf, distinct increase of P and K through nappy Comp. No influence on Ca, Mg and B.
Madejón et al., 2001[SP119]	Field trial, two years, random. block, 4 replications., M, SB, SF; calcareous , loamy sandy soil	3 different sugar beet-Vinasse-Co-Comp, 1.year: 15 Mg ha^{-1}, 35 Mg ha^{-1}, 7,5 Mg ha^{-1} ,2. year: 14, 22 and 14 Mg ha^{-1} plus 600 Kg NPK; 3. year after-effects, NPK (1000 Kg ha^{-1} N^{-1}5 $P_2O_5^{-1}$5 K_2O), 0; 300 Kg Urea (except for control);	Increase in M-yield on all Comp variations and NPK-plot in comparison to control, significant only for one Comp, with the subsequent crop (SB) increase in yield in comparison to control, significant with all variations. SB with Comp application higher yield than min. fertilisation. Comp fertilized SF higher yield than control and min. variations. Soil: no influence on pH; slight increase of salinity, significant increase of SOM-content through Comp application in most variations, same trend with average C-content of the humus extract; constant sign. increase of the humic acid fraction. CEC-increase after 2nd crop, decrease after 3rd crop, each higher than in control and min. variation. N (Kjehldahl) at the end of the trial period higher in Comp plots than min. plots and control, some significant. P-content similar on all variations.
Marinari et al., 1996[SP120]	Field trial, M, green harvest after 150 days calcareous, humuous soil	NPK. (100 Kg N ha^{-1}), StabM (30 Mg ha^{-1}) as well as MC_C (60 Mg ha^{-1}) (both incorporated 10^{-1}5 cm). Comp-amounts equivalent to min.N-variations. Combination. MC_C + NPK (30 Mg MC_C + 145 Kg NH_4NO_3 ha^{-1} (50 Kg N). 1 control. All fertilisation variations with and without herbezide application.	Generally ca. 30% reduction in yield without Atrazine, because of weed pressure, with StabM-variation –58%, no increase with NPK.
Maynard, 2000[SP121]	Field trial on 2 sites, 2 years, Tom, sandy loam, sandy terraced soil, random. block, 4	Leaf-Comp, 50 Mg/a d.m., NPK: 0, 650 and 1300 lb/A, control 1300 lb/A, cotton seed meal 2166 lb/A	1995: differences in yield only sign. compared to Comp variations without NPK, 1996: yield on Comp plots with full and half NPK-supplementation 34% resp. 19% higher than control (number of

Authors	Experimental Design	Fertilisation	Results
Effect on yield – Field trials			
	replications.		fruits/plants), same fruit weight as control. One site no statistical differences in yield between control and Comp variation without NPK. Plots with sole Comp application showed less blossom-end rot.
Maynard & Hill, 2000[SP122]	Field trial, 3 years, onions, 3 replications. (1994 just 1)	Leaf-Comp 50 Mg/a, NPK on both variations	Differences in yield between the years because of changing precipitation rates sign. lower (3% variation) with Comp plots than variations without Comp (52%). After 3 years yield of Comp plots sign. higher, also higher onion weight. Reduction of bacterial wet rot. After 3 years yield on Comp variations sign. higher, also higher onion weight. Suppression of bacterial wet rot through Comp application. Increase of SOM from 3,4 to 4,3% after 3 years.
Ouédraogo et al., 2001[SP123]	2 field trials in Burkina Faso, random. block, 4 replications., Sorghum bicolor with sowing delay; loamy sand (0-20 cm) resp. sandy-argillaceous loam (40 cm);	BWC, manure, plant residue and ashes, composted during rainy season, 0 and 10 Mg ha^{-1} resp. 0 and 5 Mg ha^{-1}.	Increase in yield 45% (5t ha^{-1}), sign. 3-fold increase with 10t ha^{-1}. Comp plots no yield reduction in spite of seeding delay for 1 month.
Pape & Steffens, 1998[SP124]	5-year field trial, 6 sites (4 eroded lessivé from loess, 1 lessivé from bunter, 1 rendzina from slate)	BWC_{fresh}, BWC_{mature} 30 Mg d.m. ha^{-1} each 1. and 3. year, min.N-fertilisation, BWC+min.-N-supplementation	Sign. lower yield in BWC+min.N-supplementation in comparison to min.N-fertilisation only during 3rd year (W-Bar → storage); Sole BWC-sites correspond to min. fertilisation on 6 sites and during 5 years.
Parkinson et al., 1999[SP125]	Field trial, 3 years, For-M-monoculture for 10 years humuous (8,8% OM) silty loam;	GWC: 0, 15, 30, 50 Mg f.m. ha^{-1} with and without supplementation (125:27:56 Kg ha^{-1})	Effect on yield compared to control varies every year. In mean of the years: sole GWC → 15 Mg ha^{-1}: +11,9%; 30t ha^{-1}: +9%; 50 Mg ha^{-1}: +13,6% GWC+min.NPK → 0 Mg ha^{-1}: 54,6%; 15 Mg ha^{-1}: +51,6%; 30t ha^{-1}: +71,3%; 50 Mg ha^{-1}: +74,8% (compared to sole min.NPK: +20%)
Petersen & Stöppler-Zimmer, 1996[SP126]	Field trial; 4 years, Ca, Pot, BR, W-W loamy sand, semi-loamy silt	BWC_{fresh} (12 – 21 days), BWC_{mature} (3 months)	No statistical differences in yield on sandy soil (96 - 103% of control). On loess by mean of all years an increase in yield on all Comp variations. (102 - 114%). BR → positive effect on yield with immature Comp Pot → positive effect on yield with mature Comp. W-W → no difference.
Petersen et al.,	Field trial; 10 years;	3 different MC_C, 1 BWC, 30 Mg f.m. ha^{-1} each and	All fertilized variations exceeded yield of control. Every kind of Comp

Authors	Experimental Design	Fertilisation	Results
Effect on yield – <u>Field trials</u>			
1996[SP127]	ecol. cultivation; CR → BR/Ca – W-W – Pot - SW/W-Bar-ley-ley lessivé from loess, loamy silt	60 Mg f.m. ha^{-1}; control [,0‘], NPK, horn meal [HM]+P+K, MC_C+HM; MC_C+⅛HM Comp application; org. fertilisation with root crops	application resulted in yield increase (108 - 121 % of control). The higher fertilisation level (60 Mg f.m. ha^{-1}) did not result in clearly higher yield. Only slight differences in yield with MC_C-variation. BWC with both application levels slight decrease in yield compared to MC (statistically not significant). In mean of all trial years the MC_C with N-supplementation resulted in 131%, with NPK 123 % and the organically fertilized 122 %.
Peverly & Gates, 1994[SP128]	2-year field trial with M silty-argillaceous loam	MWC: 0, 46, 92 and 184 Mg d.m. ha^{-1} MWSC with shredded wood: 0, 31, 62, 124 Mg d.m. ha^{-1} 1 week before planting; min. N-supplementation: 26 Kg; NPK: $114^{-1}05^{-1}05$ Kg ha^{-1}	1^{st} year → control: 3,5 Mg ha^{-1}; NPK: 5,4 Mg ha^{-1}; MW-SSC_{124}: 7,5 Mg ha^{-1}, MWC_{184}: 6 Mg ha^{-1}, 2^{nd} year → control: 3,5 Mg ha^{-1} NPK: 5,6 Mg ha^{-1}; MW-SSC $_{124}$: 7,9 Mg ha^{-1}, MWC_{184}: 8,5 Mg ha^{-1}; MW-SSC $_{31}$ und MWC_{46} ≥ NPK-plot with 114 Kg N ha^{-1}. N was the limiting factor, no toxic effects of Comp on germination and growth of M.
Pötsch, 2000[SP129]	Field trial $1992^{-1}998$, pastures with CM/LM_U /Slu/MC_C 3 cuts/year; loamy sand	Organic fertilizer: level → 1,5 LU and 3 LU each: NPK; PK; diluted Slu untreated (1:0,5 with water); $MC_{C/S}$ (Stable manure + urine); $MK_{C/P}$ (packed manure + urine), RotM (stable manure ½-rotted + urine)	1,5 LU → 65,4 – 73,9 dt d.m. ha^{-1}, <u>no significant difference</u> between different fertilisation systems, tendency of $MC_{R/A}$ and $MC_{R/T}$ towards highest yields. 3,0 LU: → 80,4 – 93,5 dt d.m. ha^{-1}, NPK-plot significant higher (except for RotM + LM_U variation). $MC_{C/S}$ and $MC_{C/P}$ showed higher yield than Slu and RotM+ LM_U as well as PK. N-efficiency of $MC_{C/S}$ and $MC_{C/P}$: 7,6 –10,7% of total N input
Roe et al., 1993[SP130]	Field trial with compos tmulch, random. block site, 4 replications.	Part I.: Capsicum annuum (bell pepper); MWC: 13, 40, 121 Mg ha^{-1}; PE-foil (without Comp); + min. NPK-supplementation: within the row and spread Part II: *Cucurbita pepo L.* (spaghetti-Pu) MWC; dried sewage sludge; shredded wood, 1 year stockpiled: 224 and 336 Mg ha^{-1}	<u>Peppers</u> → sign. higher yield on PE-foil (8,9 Mg ha^{-1}; $p<0,01$) also larger fruit with higher yield loss due to disease on PE-foil; with MWC yield 1,9; 4,6; and 7,2 Mg ha^{-1} with increasing applications of Comp-mulch. <u>Pu</u> → on PE-foil highest yield/plant and largest individual fruits; but lower total yield than on MWC and dried Slu, most yield loss trough disease on PE-foil (79% [!])
Roe et al., 1997[SP131]	Field trial, vegetables, random. block site, 5 replications. loamy sand and sand	Part I.: Capsicum annuum (bell pepper), SSC (with yard waste): 0 and 134 Mg ha^{-1} with min. NPK-supplementation of 0, 50 % and 100% of horticultural standard application. Succeeding crop: cucumber, without additional fertilisation.	<u>Capsicum</u> → <u>with Comp</u> yield 30, 35, 31 Mg ha^{-1} at 0, 50 und 100% min.NPK-supplementation , <u>without Comp</u> 19, 31 and 32 Mg ha^{-1} with 0, 50 and 100 % NPK. <u>cucumber</u> (succeeding crop) → yields higher on Comp plots (+ 18 %). At 50 % min. NPK-supplementation the yields were comparable on

Authors	Experimental Design	Fertilisation	Results
Effect on yield – Field trials			
		Part II: 0 and 134 Mg ha^{-1} SSC (a. paper waste; b. yard waste, refuse-derived fuel) with NPK 0, 50 and 100 % of horticultural standard application.	both Comp. Comp combined with low NPK-rates resulted in higher yields (pepper) than on other variations. Also on part II higher yields with cucumbers (no additional fertilizer application!).
Roe & Cornforth, 2000[SP132]	Field trial, sandy loam, Cucumis melo, then broccoli	MC_C, 22, 45, 90 Mg ha^{-1}, additionally 23N^{-1}4P-0K	Increase in yield on all fertilisation levels.
Selivanovskaya et al., 2001[SP133]	Field trial, randomised block, 4 replications., Bar, grey forest soil	Untreated Slu, anaerobically treated Slu (10 Mg ha^{-1} d.m. each), SSC (30 Mg ha^{-1} d.m.); control	Sign. SOM-increase on all trial sites in comparison to control, but below Russian and European limits. Sign. increase in yield on all trial sites in comparsion to control.
Smith, 1996[SP134]	Nationwide researchprogram in Florida	diverse MWC resp. BWC with and without Slu	Yield increases (e.g. Pot, Tom, watermelon up to 30 %)
Steffen et al., 1994[SP135]	3-year field trial; CR: Tom-SC-bean-broccoli/Ca; 3 replications. silty loam	Single application 1990: 64 Mg d.m. ha^{-1} SMC; 57 Mg d.m. ha^{-1} RotM (= je 2.700 Kg N ha^{-1} [!]), NPK. incorporation 20 cm, NPK with black PE-foil; SMC and RotM with 10 cm St mulched. With aucceeding crop only NPK-plot fertilisation according to crop.	Tom (1990) → SMC and RotM +73 % compared to NPK (p=0,05); cost/benefit-relation → SMC and RotM: 1,68; NPK: : 1,40 M (1991) → SMC and RotM +75 % compared to NPK (p=0,05); Bo (1992) → no differences in yield, Bro (1992) → yield +13% compared to NPK Kohl (1992) → no differences in yield.
Stewart et al., 1998a[SP136]	4-year field trial, CR: M-Ca-Pot-Ca Split-Plot-Design; 4 replications. fine, sandy loam	SMC: addition to ech crop 0, 20, 40, 80 Mg f.m. ha^{-1} with and without min. NPK-supplementation	M- and Pot-yield were increased through SMC-applications in the absence of anorg. fertilizers (exception M at 20t SMC ha^{-1}), Pot-yield increased independently of min. N-supplementation (increase of 38%, 82 – 96% and 26-46 % with cobs, Ca and tuber fresh weight; p=0,05). Anorg. Fertilizers increased yield more clearly than SMC. A lack of anorg. soil N was the most important limiting factor for plant growth after SMC-application.
Stoffella & Graetz, 2000[SP137]	Field trial, planting beds, randomised block, 4 replications., fine sand, Tom	Sugarcane filtercake compost 188 Mg ha^{-1}, NPK 0 and two levels	22 days after transplanting the Comp fertilized plants were larger than control, but not with higher fertilisation rates. Independently of application rates the Comp variations yielded better: Kg/plant, stronger stems, number of fruits (total and precocious), fruitweight, size of fruit.
Stopes et al., 1989[SP138]	3 lettuce varieties, yield and nitrate increase	MC_C (13,2 und 26,4 Mg f.m.) and NPK, fertilisation level → N-equivalent with 0, 80 and 160 Kg N ha^{-1}	Weight/head → MC_C increase in yield compared to control (at 160 Kg N sign.; p=0,05); min. NPK increase in yield compared to control and

Authors	Experimental Design	Fertilisation	Results
Effect on yield – Field trials			
	random. Block site; 4 replications. argillaceous loam on clay		$MC_{C/80\ Kg\ N}$ sign. (p=0,05) NO3-content in lettuce f.m. → 12% Anstieg in MC_C compared to control (not sign.); 30% increase on min. NPK plot compared to control, 20% compared to MC_C (p=0,05)
Timmermann et al., 2003[SP139]	Long-term compost trial (8 resp. 5 years): duofactorial split-plot design with 12 variations at 4 replications each, replications. random. → 48 plots per trial 6 sites : lS, uL, uL, utL, uL, sL CR: Ma – W-W – W-Bar	Comp application: 0; 5; 10; 20 Mg ha^{-1} N-supplementation level N0: no additonal N-application level N1: 50 % the optimal N-application level N2: 100 % the optimal N-application on basis of the Nmin-content of the soils as well as further aspects, like pre-crop etc. (comp. nitrateinformationservice - NIS). Complete removal of crops.	Yield increase with higher Comp application rates, also at application rates of 20 Mg ha^{-1} d.m. (K3), which is considered excessive by judgement of GAP, because of the positive nutrient balance. The mean yield increase with Comp applications from 5 to 10 Mg ha^{-1} d.m. (level K1 and K2) and reduced N-supplementation (between levels N1 and N2) is approx. 5 – 8 %. Besides the nutrient supply, the ameliorative effects of Comp, regarding soil structure and biology, contribute to these results on claybased soils, whereas on sandy soils the predominant amelioration effect stems from improvement of waterbalance and reduction of drought stress. With regular conditions of production, where St is used as compensation regarding the humusbalance, such explicit effects (as with Comp accliaction) on yield are not to be expected.
Vogtmann & Fricke, 1989[SP140]	1-year field trial kohlrabi random. block site soil: ???	BWC 60t ha^{-1} (=60 – 90 Kg N ha^{-1}); NPK 70 Kg N ha^{-1}; 0; with 0, 25, 50 and 100% addition of shredded bark	Sign. increase in yield (p=0,05) compared to control, no difference between BWC and NPK (neither with tubers not leaf yield).
Warman & Havard, 1997[SP141]	3-year field trial 2 crops Ca, carrot, 5 replications. sandy loam, yield, vitamin- and mineralcontent	mature MC_C and MC_{Pou} from cattle or poultry, 170 Kg N ha^{-1} for carrots, 300 Kg N ha^{-1} for Ca (assumption: 50 % available). NPK-plot according to conventional fertilisation recommendation	Carrot → sign. higher yield in MC_C only during 1st year. Ca → Sign. higher yield in MC_C only during 1st year. During 3 years no detectable difference in yield and vitamin content.
Warman, 1998[SP142]	7-year field trial 1990 – 1996 (continued), CR: Ca-onions-M-Pot-carrot-M-broccoli no statistics sandy loam	MC and/or, BWC, GWC + St; calculation of amounts on basis of the assumption: 50 % N-availability; NPK – conventional cultivation	Since 1993 yields of Comp plots are higher or same as on NPK. Pflants with high N-demand (broccoli, onions, cauliflower) did better with NPK, Tom and carrots did better on Comp. Larger marketable fraction of carrots with Comp (Comp: 76%; NPK: 67 %).

Authors	Experimental Design	Fertilisation	Results
Effect on yield – <u>Field trials</u>			
Warman, 2003[SP143]	Continuation of above trial (1999-2000)	MC and/or, BWC, GWC + St; calculation of amounts on basis of the assumption: 50 % N-availability; NPK – conventional cultivation	Yield of onions is sign. higher with Comp application (contrary to Warmann, 1998); Differences with other crops inconsistent.
Weissteiner, 2001[SP144]	8-year field trial (1993–1999), CR: Corn-M-So- W-W – W-Bar – FE – Wra – Corn-M – W-W no statistics loamy silt	BWC/MC partially +/– compoststarterbacteria [MC_B], 12 – 24 Mg d.m. ha^{-1} and Jahr, 7 variations; (with and without min. NPK-supplementation, with and without application of chemical-synthetic fertilizers), standard=customary, conventional NPK (NPK without compost)	<u>1st year Corn-M</u> no difference between variations <u>3rd year W-W</u> and <u>4th year W-Bar</u> variations with Comp and no application of chem-synthetic fertilizers show yield reduction, <u>5th year FE</u>: balanced yield. <u>6th year WRa</u>, <u>7th year M</u> and <u>8th year WW</u> → similar yield as W-W and W-Bar.
Whyatt & Putwain, 2003[SP145]	2 years, 2 sites, 3 replications, CR1: Pot-bean; CR2: Bar-O	Year 1: 0, 20, 40 Mg ha^{-1} + customary fertilisation, 40 Mg ha^{-1} without additional fertilisation; year 2: Comp application increased by 50 %	1st year Pot yield: -29,3% no anorg. fertilisation, -8,11% with anorg. fertilisation; N-content of tubers with sole comp application – 25%. No difference in Bar yield. 11% less N-content in Bar with sole Comp application. 2nd year: beans: yield –6%, N-content + 5%; O: yield – 18% (no anorg. fertilisation) resp. –10% (with anorg. fertilisation). N-content – 2% (not sign.).
Wong et al., 1999[SP146]	Chinese cabbage, M, loamy soil	MC, 0, 10, 25, 50 and 75 Mg ha^{-1}	Partially sign. increase in yield, highest yields with 25 Mg ha^{-1} for M, 50 Mg ha^{-1} for Chinese cabbage. Sign. increase in porosity and hydr. conductivity, decrease of bulk density. Increase of SOM, macro- and micronutrients (Cu, Zn, Mn) in soil according to fertilisation applications.

TABLE 3-11: YIELD EFFECT IN POT TRIALS – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results
Effect on yield – Pot trials			
Abou-Hadid et al., 2001[SP147]	greenhouse, 2 years, random. block, 5 replications., cucumber	Poultry manure and cucumber waste, 50 Kg/plot (12x1m), control	Comp application causes: increase of N-content in cucumbers: early stage 34%, maturation stage 86% above control. P-concentration: 73% resp. 260% above control. K-concentration: 93% resp. 99% above control. Increase in yield during whole growht period : 17,6% (early stage) and 15 % at maturation (fresh weight).
Bernal et al., 1998[SP148]	Greenhouse experiment five variations Calcareous silty loam soils Comp and N-mineralization in various stages of maturation, Lolium perenne	(S) without fertilisation, (S) with 20-20-20 NPK mineral fertilisation; (S+I) soil with (I), (S+E) soil with + E; (S+M) soil with (M) Soil (S) Comp: Comp from Slu with cotton waste (46:54 f.m.), 3 diff. stages: (I) initial blend, (E) end of active phase, (M) mature comp.	N-immobilization with immature Comp (N-deficiency in plants). These Comp are able to re-mineralize N at a later stage (from the immobilized pool). The greatest N-efficiency was found for mature Comp (M) (high NO_3-content).
Fauci & Dick, 1994[SP149]	(4x4x4), soil x org. waste (in greenhouse) x N-fert. (in greenhouse) pots with PE-bags (2kg d.m.) Maize harvest 35 days after planting.	Both contain wheatSt + one of the following treatments in 2-year intervals: (i) anorg. N (34 Kg until 1966 and 90 Kg ha^{-1} from 1967 – 1989), (ii) cattle manure straw bedding (22,4 Mg d.m. ha^{-1}), (iii) pea/vine-waste (2,24 Mg d.m. ha^{-1}) or (iv) St without addition (control). Organic waste (a) pea/vine-waste, (b) MC_C (c) MKG. Various N-fertilisation with 0, 200, 400 and 400 mg N/2kg both to plant 1, but in sum cumulative 0, 400, 800 and 1600 mg N/2 Kg both (3 consecutive crops)	No additional min. N, waren die Bd., welchen lange Zeit org. Abfälle zugeführt wurden (Mist oder Erbsen-Reben-Abfälle) produktiver und hatten höhere C und N-Gehalte als Bd. mit min. Düng oder keiner Düngung. Obwohl Erbsen-Wein-Abfälle und Rindermist ähnliche C/N-Gehalte hatten (21 und 24 resp.), immobilisierte Rindermist N, während Erbsen-Wein-Abf. eine nachhaltige Netto-N-Mineralisierungsrate aufwies. Das C/N-Verhältnis mag nicht immer der ideale Indikator für die N-Verfügbarkeit sein, in diesem Falle beachte man auch den Lignin-Gehalt (6 % für Erbsen-Wein, 28 % für Rindermist). Unter Glashausbedingungen konnte bei Rücknahme der min N-Düngung die Produktivität am besten durch Übergang auf Geflügelmist bzw. Erbsen-Wein-Abfälle gesichert werden.
Gajdos, 1997[SP150]	greenhouse, (day 16°C, night 12°C, 90 % rel humidity, 16.000 bis 20.000	MWC, BWC, 8 – 12 weeks Blend with commercial peatsubstrate 0, 10, 20, 30 and 40 % vol., 60 – 70 % d.m.	Keimung: Salat- und Rettich im Vergleich zu konventionellen Wachstumsmedien vor allem bei MüK verzögert, Lolium perenne, Gartenkresse und Tagetes unbeeinflusst.

Authors	Experimental Design	Fertilisation	Results
Effect on yield – <u>Pot trials</u>			
	Lux, 16 hrs day) Lactuca sativa, Lepidum sativum, Lolium perenne, Raphanus sativus and Tagetes teniufolia ..., yield (f.m. and d.m.) after 31 days,	Liquid micronutrient fertilizer	Frisch- und Trockenmasseanalysen: Torfsubstrat mit BAK nach einem Monat gleiche oder höhere Erträge, insbesondere bei Zugabe flüssiger Dünger. Torfsubstrat mit MüK deutlich niedrigere Erträge Kompost als „unausgeglichener Hauptlieferant“ von Nährstoffen braucht nur geringe Menge an zusätzlichem flüssigen Mikronährstoffdünger
Greilich & Jänicke, 1988[SP151]	6 month vesseltrial (5,5 Kg soil, 3 soiltypes: silty loam, sandy loam, sand) CR: green oats, perko sunflower Assessment for total yield of the 3 crops	MWC (waste:Slu = 4:1), 4 months, blended 3 times StabM (well rotted), min. N-supplementation (0,5 + 0,4 g) Min. PK-supplementation for all Org. fertilisation in relation to C-Gehalt, variations: O, MWC 20, StabM 20, MWC 40, StabM 40, MWC 20+N, StabM 20+N, MWC 40+N, StabM 40+ N,	N-utilization = N-extraction (extraction is difference of total extraction minus extraction of control) / N-application 100: For sole Comp (single and double application each): highest utilization with sandy soil: betw. 45 resp. 37%; with sandy loam: 21 resp. 24%; with silty loam: 30 resp. 26%. With combined fertilisation (Comp+mineral; single and double application each): utilization with sandy soil: 42 resp. 36%; with sandy loam: 32 resp. 18%; with silty loam,: 44 resp. 33%. With MWC 40, StabM 40 N from StabM 40 was utilized better In mean of the 3 soils and the 2 application rates of MWC: MWC 90% higher d.m. yield than control, achieves 85% of the min-N-variation and 66% of the StabM variation. Mostly sign. higher effect of StabM, because of 50% higher total N application through StabM and more intensive mineralization of StabM. With the lower Comp application rates, with and without mineral supplementation, the N-utilization rate is comparable with the lower StabM application rate.
Herrero et al., 1998[SP152]	greenhouse, (4 months) vessel sandy loamy soil, pH 8,38, 2,27% OM, Lolium perenne	14 different org. products (composts, sludges and manures) with application rates of 25 and 50 Mg ha^{-1} Comp and C = 0-variation with 4 applications of min. fertilizer. N1 50, N2 100, N3 200 N4 300 Kg N ha^{-1} as ammoniumsulphate,	Yieldweights were sign. higher than control C on N2, N3, N4, E1-E5, E7, E10-E13 (25 and 50 Mg ha^{-1}), E8, 9, 14 (50t ha^{-1}). Application org. products gnerally increased yield, but not always according to application rate. The min. fertilisation increased yield, most on N3 but not on N4, but N3 was lower than the highest yield with org. products.

Authors	Experimental Design	Fertilisation	Results
Effect on yield – Pot trials			
		products: E1: (raw CM), E2 (MC_C), E3 (raw GM), E4 (MC), E5 (SSC), E6, E7 (MWC), E8 (MK_P and pomace), E9 (Comp from citrusbranches), E10 (commercial Comp mainly from cocoa), E11 (commercial Comp mainly from pomace), E12 (commercial Comp mainly from MC_C), E13 (worm Comp), E14 (commercial GWC).	
Hountin et al., 1995[SP153]	greenhouse vesseltrial (20 Var., 4 replications.) loamy sand, lime application, low SOM Bar (Hordeum vulgare)	Peat/shrimp-waste-Comp 0, 60, 120, 240, 480 Mg ha^{-1} (moist),4 NPK-application amounts: Ammoniumnitrate (33 % N), triple superphosphate (45,8 % P2O5) and potassiumchloride (60 % K2O) at following amounts: 0, 0,25x, 0,5x and 1x which is x=70 Kg N ha^{-1}, 80 Kg P2O5 ha^{-1} and 90 Kg K2O ha^{-1}.	Comp applications increased growth of Bar Highly sign. influence of Comp on straw and grain yield. Above Comp applications of 240t ha^{-1} no yield increase. The yield increase was better on Comp+NPK, compared to the individual fertilisation variations.
Hue & Sobieszcyk, 1999[SP154]	greenhouse soil: 58 % clay, 35 % silt, 1,85 % Corg, 0,15 % Nt Tom (42 days)	Pelletized chicken manureSlu, untreated biowaste, unfinished GWC, „ground fresh corn stovers“ and commercial peat. Soil-biowaste-blend: for vegetable waste 25 and 50 % vol, für animal waste 2,5 and 5 % urea 0, 70 and 210 mg N/Kg.	Growth media with kitchen waste (C/N-ratio of <15), released anorg. N and caused an increase of d.m., several times more than that of control. Growth media with a C/N-ratio of > 20 immobilized anorg. N, reduced plant-growth and caused a N-lack in Tom (N-concentrations of < 2,0 %) and chlorosis
Lopez et al., 1998[SP155]	greenhouse, vesseltrial Pelargonium zonale, 8 per variation plantheight on day 45 and 100, fresh- and dryweight of 4 plants on day 45; weighing, drying and analysis on day 100.	(C), commercial substrate from peat and min. fertilizer, (M) commercial substrate from MC and composted waste from cotton ginning, (M2P1) M and peat 2:1 (vol), (M1SW1P1) M, MWC (49 days on open windrows with 6 blendings, then 60 days maturation) and peat 1:1:1 (vol),	All Comp substsates caused hypogenesis of the verursachten eine Unterentwicklung der Geranien im Vergleich zur Kontrolle (ev. verschlechterten physikalische Eigenschaften, N-Immobilisation auf Grund des hohen C/N-Verhältnisses der Rinde und vielleicht einem Mangel an verfügbarem P wegen dem hohen Ca-Gehalt und hohem pH) Die N-Düngung und die Verlängerung der Kultivierungsperiode verringerte die Unterschiede.

Authors	Experimental Design	Fertilisation	Results
Effect on yield – <u>Pot trials</u>			
		(M1B1) M and bark (2 years matured, but not composted) 1:1 (vol). Manure and cottonwaste composted separately, matured for one year; From day 45 sprinklers with 150 mgN/l-Lösung,	
Lütke-Entrup et al., 1989[SP156]	longterm (2 years) Kick-Brauckmann (9 liters) welsh rye grass, winter-Ra, oats (O), phacelia, lettuce and kohlrabi; ornamental plants (germination tests)	BWC: (windrow, 16 weeks, C/N ca. 20:1, 0,4-0,6 % Ntot, from that ca. 10 % NO_3 and NH_4, 0,28-0,41 % P_2O_5, P_2O_5-available 29 mg/100g, 0,5-0,7 % K_2O, K_2O-available 194 mg/100g, 0,41-0,62 % MgO. arsenic-increased Min N-supplementation: 120 Kg N ha^{-1}, welsh ryegras + 60 Kg N ha^{-1} after 1. cut, urea: 20, 60 and 100 Kg N ha^{-1}. Min PK–supplement	with <60 % Comp generally increase of yield addition of P- and K-single fertilizers had no effect on d.m.-yield, except for 2nd cut of ryegrass. Increasing N-application rates resulted in yiled increase only with <40 % Comp. similar effect through dehydr. slurry: <50 % Comp as well as 10 and 20 % dehydr. slurry resulted in distinct increase of yield. Similarly the addition of the liquid fertilizer Basfoliar 12-4-6. Barkmulch and barkComp caused a decrease in d.m.-yield. Positiv effect of 5 % St. No negative effect through barkmulch and barkComp with an addition of peat. No effect through bentonite. Pure Comp: N-supply and PK-supply (?!) not sufficient. NPK-fertilizer addition recommended.
Madrid et al., 1998[SP157]	greenhouse, sandy soil Tom leaf samples after 30, 87 and 192 days; fruitsamples after 127 and 185 days. yield documentation: number, weight and average fruitweight every 3 days.	Control without org. fertilizer MWC: OM 26 %, N 0,6 %, P2O5 0,62 %, K2O 0,55%; 21 Mg d.m. ha^{-1} Commercial Comp from sheepmanure: OM 52 %, N 3,4 %, P2O5 0,5 %, K2O 2,39 %; 5 Mg d.m. ha^{-1} NPK for all variations: 181 Kg ha^{-1} N, 22 Kg ha^{-1} P2O5, 108 Kg ha^{-1} K2O.	The average fruit-weight and the yield increased considerably with the application of commercial Comp (204 g, 104,6 Mg ha^{-1}), in contrary to MWC, which increased yield only slightly (180 g, 92,3 Mg ha^{-1}) in comparison to control (166 g, 90,7 Mg ha^{-1}). Compared to control, the org. fertilisation caused an increase in SOM and soluble nutrients. The Comp applications increased the K-, Mg- and Ca-content of Tom-fruit and Tom-leaves and accordingly the EC of the Tom-juice was increased as well. The Comp applications had no influence on N- and P-content of leaves and fruit.
Maher, 1994[SP158]	greenhouse (5 months) pots (4 liters) greybrown	SMS Spent Mushroom Substrate (4,5 to 72 Kg d.m. m^{-3} = 25 to 400 Mg FS ha^{-1})	<u>1st harvest</u>: positive influence of the additives (up to 50 Mg f.m. ha^{-1}), beyond that a negative effect probably because of increased conductivity;

Authors	Experimental Design	Fertilisation	Results
Effect on yield – Pot trials			
	podsol, with argillaceous-loamy texture Lolium perenne, 4 harvest dates	Concurrent experiment: supplementary fertilizer (PK as well as Calzium Ammonium Nitrate)	Totalyield (DS from 4 cuts): positive effect up to highest addition (400 Mg f.m. ha^{-1}), reduction of conductivity through plantextraction and leaching. No effect from P, K-application
Marcos et al., 1995[SP159]	vesseltrial, silty clay, Tom	4 Comp types, good chemical properties	3 of the 4 Comp (Comp 1 possibly phytotoxines) increased yield in comparison to control.
McCallum et al., 1998[SP160]	greenhouse, sandy loam; N-Index 0. SW (since 1980) three replications. in boxes (23 x 16,5 x 5 cm), 24 seeds per box. Germination rate on day 20, d.m.-yield on day 36.	control: only soil 2 GWC: 17 months, mature, OM 54,36 %, Nt 1,38%, Ct 31,78 %, C/N 22,78; 7 weeks, instable, OM 28,09%, Nt 1,38 %, Ct 16,3%, C/N 22,78; 3 applications (100, 200, 300 Mg ha^{-1}), 3 intervals between application and seeding (0, 1 and 2 weeks), control.	Immature Comp: higher germinationrate caused by the cryoprotective effect during a cold snap. Mature Comp: slight, but not constant lowering of the germination rate. Significant germination improvement through higher application rates. A cold snap lowered the germination rate on all variations between application and seeding, however the seeds with immature Comp were less affected than the others. Mature Comp increased d.m.-yield an all variations, immature compost lowered d.m.-yield. The application rates had no influence on d.m.-yield. Based on the relatively low C/N-ratio of immature Comp, the influence on the d.m.-yield is based on the presence of phytotoxins.
Negro et al., 1996[SP161]	Field trial, 32 l-pots, poor soil Sorghum bicolor vr. Dale (Sweet sorghum)	Sewage Sludge (SS) Sweet sorghum residues(SSres), pig manure (PM), Slu Slu (15 Mg ha^{-1}) and PM (15 Mg ha^{-1} and 30 Mg ha^{-1}) from blended windrows, NPK-supplementation towards equal application rates. Min. NPK sole application Control: without fertilisation 2 irrigation variations	SSres/PM (30 Mg ha^{-1}): highest yield SSres (total and d.m.) in both irrigation variations, higher than traetments with min. NPK (37% increase of air dried d.m.); SSres/PM (15 Mg ha^{-1}): similar yield as min. NPK; SSres/SS (15 Mg ha^{-1}): lowest yield except for control without fertilisation; No difference in sugar yield.
Prasad & Maher, 2001[SP162]	2 experiments, 11 cm pots, temp >15°C; peat, Tom	1: 7 blending levels from 5 – 50% GWC/peat v/v; 100% GWC, 100% peat 2: 3 various GWC, blends: 0, 10, 20, 50% v/v	GWC-addition increased bulk density and lowered pore volume. 50% addition lowered the water availability. pH-increase on all substrates. Experiment 1: 50%-rate no influence on initial growth, but nhibition on later growth (decreased N-availability); Experiment 2: 50%-rate slight growth-

Authors	Experimental Design	Fertilisation	Results
Effect on yield – <u>Pot trials</u>			
			inhibition during early growth, with 2 GWC, strong effect on 3rd, 20% addition had no effect on plant growth
Shiralipour et al., 1996[SP163]	greenhouse, plasticpots, three typical californian soils broccoli, lettuce	BWC 1:1 vol ; 3,32 % N, pH 6,4, C/N 10 0, 15, 30 and 60 Mg d.m./acre	All Comp applications increased yield and height of broccoli, as well as the d.m. of lettuce shoots. Optimal application rates on loam and argillaceous loam were 30 and 60 Mg d.m. $acre^{-1}$ for broccoli and 15 and 30 Mg d.m. $acre^{-1}$ for lettuce, on loamy sand between 30 and 15 Mg. With high Comp application rates broccoli had less phytotoxic symptoms than lettuce, possibly because of better salt tolerance.
Stoffela & Graetz, 1996[SP164]	greenhouse, plasticpots 3,7 l 10 replications. Tom 25 days partial experiment 2	Comp. from filter cake from sugarcane processing; Comp Sandy soil Comp: soil 1:1 (vol)	Increase in diameter, higher plants, more sprout- and rootmatter as well as larger sprouts: root-ratio with (a) and (c)
Valdrighi et al., 1996[SP165]	plasticpots, 1,8 Kg soil, sandy soil, pH 7,6; SOM 1,43 %; N 0,11 %, K 0,2 %, Kverf. 63 mg/Kg chicory	Comp-humic-substances appl. rates 0, 250, 500, 1000, 2000, 4000, 8000 mg/Kg soil. block with KCl-solution at same application rates as Comp-humic-substances. Tween 80 with 0, 100, 200, 1000, 2000 mg/Kg soil. Tween 80 combined with Hoagland's mineralsolution at a ratio 10:100. Comp-humic-substances 0, 1000, 2000 mg/Kg soil with 10 % Hoagland's mineralsolution.	Comp-humic-substances >1000 mg/Kg sign. increased yield weight, was not only based on the K-content of the humic acids. (KCl-plots showed no change in comparison with control). The cause may be changes in membrane permeability, which are affected by the humic substances. Similarly high yields with Tween 80 at application rates of 100 and 200 mg/Kg. Tween 80 with Hoaglands solution did not result in a change of the chicory-biomass.
Vogtmann et al., 1993[SP166]	vesseltrial (40 and 80 l) glasshouse tomatos	Potting soil (60 % BWC, 25 % peat, 15 % loamy sand) (KKS-O) Commercial potting soil (40 % Ton, 60 % peat) (EE)	Fertilisation with (a): lowest yield and marketable crop, Yield of (c) in range of (b); Sensory analysis Tom: (a) before (c) and (b)

Authors	Experimental Design	Fertilisation	Results
Effect on yield – <u>Pot trials</u>			
		peat) (EE) fertilisation: urea with irrigation, (KKS-O); 15-5-25-5 with irrigation, (EE); (KKS-O) without N-irrigation but with hornmeal addition	
Zachariakis et al., 2001[SP167]	vesseltrial, field trial, 2 varieties grapevines, calcareous loamy sand,	humusfraction extracted from mature olivleaf-Comp, 50 resp. 500 ppm humic-substances, control	The addition of humic substances supports plant growth, (root- and shoot-dryweight) as well as the chlorophyllcontent of the leaves. Nutrient enrichment in roots and leaves P, K and Ca (mostly significant), also Fe, Mn and Zn.

3.4 *Compost and nutrient supply*

3.4.1 Phosphorus, Potassium, Magnesium

Especially relevant for the evaluation of nutrient supply with compost is the ratio of the total and the fraction directly plant available in the course of one to three vegetation periods.

The latter are determined in a water or neutral salt extract or using “exchanging agents” simulating the ion exchange between soil solution and clay-humus complex.

TABLE 3-12: PHOSPHORUS AND POTASSIUM – MEDIAN AND FREQUENCY PRIORITIES IN BIOWASTE - AND COMPOST OF GREEN CUTTINGS, SEWAGE SLUDGE AND MANURE

		BAK	**GK**	**KSK**	**Manure compost**
		[% TM]			
ZAS (2002[p168]) n = 17500	P_2O_5 gesamt	0,65 0,34 – 1,08 (10%-90%il)			
Zethner et al. (2001[SP169])	P_2O_5 gesamt	1,0 0,6 – 1,2	0,65 0,48 – 0,8		
Peyr (2000[p170])	P_2O_5 gesamt	0,95 0,70 – 1,3			
Charonnat et al. (2001[p171])	P_2O_5 gesamt	0,94 (n=41)	0,69 (n=272)	3,25 (n=153)	2,45 (n=27)
ZAS (2002[p172]) n = 17500	K_2O gesamt	1,08 0,55 – 1,68 (10%-90%il)			
Zethner et al. (2001[SP173])	K_2O gesamt	1,5 1,25 – 1,75	1,1 0,8 – 1,5		
Peyr (2000[p174])	K_2O gesamt	1,31 0,99 – 1,6			
Charonnat et al. (2001[p175])	K_2O gesamt	1,5 (n=39)	1,25 (n=272)	0,62 (n=153)	3,55 (n=27)
ZAS (2002[p176]) n = 17500	MgO gesamt	0,71 0,34 – 1,31 (10%-90%il)			
Zethner et al. (2001[SP177])	MgO gesamt	2,2 1,8 – 2,8			
Peyr (2000[p178])	MgO gesamt	1,52 1,0 – 2,1			
Charonnat et al. (2001[p179])	MgO gesamt	0,88 (n=38)	0,56 (n=268)	0,51 (n=141)	1,28 (n=26)
Zethner et al. (2001[SP180])	CaO gesamt	9,9 7,9 – 12,3			
Peyr (2000[p181])	CaO gesamt	6,6 4,0 – 8,6			
ZAS (2002[p182]) n = 17500	CaO gesamt	4,0 2,0 – 7,6 (10%-90%il)			
Charonnat et al. (2001[p183])	CaO gesamt	7,55 (n=37)	4,97 (n=278)	4,58 (n=132)	5,36 (n=22)
Zethner et al. (2001[SP184])	P_2O_5 CAL	0,26 0,18 – 0,31			
Amlinger (1997[SP185])	P_2O_5 CAL	0,44 – 0,53	0,33 – 0,48		
Peyr (2000[p186])	P_2O_5 CAL	0,29 0,21 – 0,41			
Zethner et al. (2001[SP187])	K_2O CAL	0,6 0,5 – 0,75	0,4 0,25 – 0,6		
Amlinger (1997[SP188])	K_2O CAL	1,07 – 1,39	0,84 – 1,1		
Peyr (2000[p189])	K_2O CAL	0,96 0,66 – 1,3			

TABLE 3-13: TYPICAL RANGES OF PLANT AVAILABLE MAIN NUTRIENTS IN BIOWASTE AND GREEN COMPOST (MG/L F.M.) (STÖPPLER-ZIMMER ET AL., 1993[SP190]; ZAS, 2002[p191])

Nutrient		Biowaste compost	Green compost
		mg l^{-1} f.m.	mg l^{-1} f.m.
$N_{lösl}$	ZAS (2002[p192]) median; n = 17500	216 (Med) 24 – 655 (10% - 90% percentile)	
N ($CaCl_2$)	Stöppler-Zimmer et al. (1993[SP193])	100 - 400	50 - 200
P_2O_5 (CAL)	ZAS (2002[p194]) median; n = 17500	934 (Med) 409 – 1644 (10% - 90% percentile)	
P_2O_5 (CAL)	Stöppler-Zimmer et al. (1993[SP195])	1000 - 2000	500 - 1400
$K_2O_{lösl}$	ZAS (2002[p196]) median; n = 17500	3306 (Med) 1490 – 5655 (10% - 90% percentile)	
K_2O (CAL)	Stöppler-Zimmer et al. (1993[SP197])	3000 - 7000	1000 - 3000
$MgO_{lösl}$	ZAS (2002[p198]) median; n = 17500	216 (Med) 137 – 343 (10% - 90% percentile)	
Mg ($CaCl_2$)	Stöppler-Zimmer et al. (1993[SP199])	150 - 300	150 - 300

It is obvious that the nutrient ranges fluctuate on account of the great variety of input materials and the varying maturity and screening degrees of the investigated composts. Despite of this fact especially in the range of main nutrients good forecasts and assessments can be made for their nutrition efficiency on account of the achieved experiences. The data in Table 3-12 and also other tests (e.g. Boisch,1997[FA200]) show that biowaste composts contain higher nutrient concentrations than green composts. Compost from sewage sludges have a distinctly higher P concentration on account of phosphate separation, mostly higher N levels but very low potassium contents.

Contrary to nitrogen most of the authors assume a nearly complete attribution of the fertilising effect in the course of up to 3 vegetation periods with phosphor and potassium. Table 3-14 summarises the concentration ranges of the total and available nutrients in biowaste and green compost.

TABLE 3-14: LIMITS OF VARIATION OF TOTAL AMOUNTS AND PLANT AVAILABLE AMOUNTS FOR P, K AND MG IN COMPOSTS

	Total amounts (mg Kg^{-1} d.m.)	supply with 20 Mg compost ha^{-1} (Kg ha^{-1})	plant available amounts (mg Kg^{-1} d.m.)	supply with 20 Mg compost ha^{-1} (Kg ha^{-1})
Phosphorus	1000-5000	$20^{-1}00$	200-2000	4-40
Potassium	$5000^{-1}2000$	100-250	$1600^{-1}0000$	32-200
Magnesium	1200-4000	25-80	100-600	$4^{-1}5$

Only few papers are dealing with the importance of trace nutrients applied with compost. A exemplary survey on the contents of some trace nutrients gives Table 3-15.

TABLE 3-15: TRACE ELEMENTS – MEDIAN AND RANGE IN BIOWASTE AND GREEN COMPOST, SEWAGE SLUDGE AND MANURE COMPOST

		BAK	GK	KLS	Manure compost
			[mg Kg^{-1} TM]		
Kehres 1991	Fe	12000		---	---

Charonnat et al. (2001[p201])	Fe	11640 (n=12)	6600 (n=27)	8450 (n=25)	--- ---
Kehres 1991	Mn	580		---	---
Charonnat et al. (2001[p202])	Mn	430 (MW) (n=10)	262 (n=32)	294 (n=26)	--- ---
Kehres 1991	B	26		---	---
Charonnat et al. (2001[p203])	B	--- ---	52 (n=15)	21 (n=13)	--- ---
Kehres 1991	Mo	3		---	---
Charonnat et al. (2001[p204])	Mo	1,8 (MW) (n=9)	1,6 (n=19)	1,2 (n=10)	--- ---
Charonnat et al. (2001[p205])	Se	0,5 (n=14)	0,4 (n=32)	2,8 (n=12)	--- ---
ZAS (2002[p206])	Zn	183		---	---
Charonnat et al. (2001[p207])	Zn	242 (n=27)	170 (n=119)	294 (n=99)	600 (n=22)
ZAS (2002[p208])	Cu	45		---	---
Charonnat et al. (2001[p209])	Cu	89 (n=25)	44 (n=120)	119 (n=99)	215 (n=22)

Dependent on the compost type and soil properties the nutrient effect (efficiency) can vary in wide ranges.

Ebertseder (1997[FA210]) proved e.g. that the P efficiency on slightly sandy soils amounted to 70% however on soils with pH values > 7 only approximately 20%.

A series of investigations proved increasingly available portions of phosphorus and potassium on soils fertilised with compost (e.g. Martins & Kowald, 1988[FA211], v. Fragstein et al., 1995[FA212], Hartl et al., 1998[FA213], Pinamonti, 1998[FA214], Kluge, 2006). It must be considered that in these tests sometimes a surplus of compost quantities based on the experimental design, but partly to compensate the low N-availability. Locations with a regular compost application proved to have higher contents of soluble phosphates and potassium dependent on compost rates applied (Ebertseder & Gutser, 2003[SP215]b)

According to Ebertseder & Gutser (2003[SP216]b) approximately 35 % of phosphorus in compost can be assumed to be plant extractable (CAL-extract) and approx. 20% are organically bound.

Potassium has a soluble portion of over 75% (CAL-extract). Compost prove to have a relatively good P-fertilising effect, yet still less effective compared to mineral fertilisers.

The solubility of phosphorus (like the one of heavy metals) in compost is based on the actual conditions like pH value and redox potential (Berner, 2003[SP217]). Do these change with the incorporation into the soil the soluble components of these materials will change, too. Thus it is not possible to conclude from values in compost on the later solubility characteristics when applied on soil.

Kluge (2003[SP218]) proved in field trials on six locations over several years also the fertilising efficiency related to P- and Potassium supply (Table 3-16):

TABLE 3-16: FERTILISING EFFICIENCY OF P AND K SUPPLY BY COMPOST AT AN APPLICATION RATE OF $6^{-1}0$T D.M. HA^{-1} Y^{-1} (KLUGE, 2003[SP219])

	Phosphorus P_2O_5	Potassium K_2O
Supply - absolute (Kg ha^{-1})	60 – 80	110 – 130
relative efficiency of total fertilisation - (% supply)	30 – 50 %	40 – 55 %
- increased plant uptake	4 – 8 %	3 – 6 %
- Increase of the soluble pool in the soil	25 – 40 %	35 – 50 %
relative efficiency of mineral fertilisation		
- in the year of application	15 – 20 %	50 – 60 %
- over 10 to 20 years	40 – 50 %	100 %

With an annual compost application of 6 to 10 t d.m. ha^{-1} y^{-1} an annual input of 60 – 80 Kg ha^{-1} P_2O_5 and of 110 - 130 Kg ha^{-1} K_2O is applied (see Table 3-16). While the consumption by harvested products is at maximum 10% of the supply a distinctly increase of plant available pool in the soil is achieved. Considering phosphorus this portion increases to 25 – 40% and regarding potassium to 35 – 50% of the supply by compost. Hereby a relatively good correlation exists between nutrient supply by compost and the plant available pool in the soil. Also mineral fertilisers do not have a fertilising efficiency of 100%. In the application year the efficiency of phosphorus fertilisers ranges only from 15 – 20%, potassium fertilisers from 50 – 60%. Considering this fact the total fertilising efficiency with compost can be estimated as high at levels of 30 – 50% for phosphorus and of 40 – 60% for potassium.

According to the BGK e.V. (2005) phosphate (P_2O_5) and potassium (K_2O) serve as basic fertilisation in crop rotation.

TABLE 3-17: CONTRIBUTION OF COMPOST SUPPLYING NUTRIENT TO SOILS AND PLANTS

Compost type:	Concentration (1) [Kg Mg^{-1} f.m.]			Fertilisation (2) [Kg ha^{-1}]		
	P_2O_5	K_2O	CaO	P2O5	K_2O	CaO
Mature compost	4,1	6,8	30	160	270	1.200
Fresh compost	4,8	7,7	28	180	300	1.100
made assumptions						
Compost type:	(1): content [% d.m.]			(2): application quantity [Mg ha^{-1}]		
	P_2O_5	K_2O	CaO-equ. *)			
Mature compost	0,64%	1,1%	4,7%	25 Mg d.m. (40 Mg f.m.) every 3 years		
Fresh compost	0,73%	1,2%	4,4%			

*) as alkaline effective materials

TABLE 3-18: NUTRIENT BALANCE OF A 3-YEARS CROP ROTATION WITH PURE COMPOST FERTILISATION (FROM BGK E.V., 2005)

Crop rotation:	P_2O_5	K_2O	CaO	
	Nutrient demand [Kg ha^{-1}]		Targeted pH	Preservation liming [Kg CaO ha^{-1}]
Sugar beet	59	147	5,6 – 7,0 depending on soil type 1)	600 – 1.600
Winter wheat	88	160		
Spring barley	56	42		
Sum demand	**203**	**349**		
Supply with compost (**30 Mg d.m.**)	~ 200	~ 335	~ 1.300	
Balance	**+/– 0**	**+/– 0**	**+700 to –300**	

1) target pH-values at supply stage C of the soil: sand: 5.6; loamy sands to silts: 6,0; strongly sandy loams to loamy silts: 6,4; sandy, silty loams to loams: 6,8; silty clay loam to clay: 7,0.

According to Beisecker et al., 1998[SP220] phosphorus and potassium are usually the limiting factors of compost supply. Specifically for sewage sludge (composts) the P content limits the possible application rate. Beisecker et al. (1998[SP221]) judge a compost rate of approx. 10 Mg d.m. ha^{-1} and year for both N, P and K beyond crop demand.

This assumption cannot be agreed upon unqualified considering the example of an average balance shown in Table 3-18. However in long-term regular application systems quantities of over 10 Mg d.m. ha^{-1}y^{-1} would in many cases also lead to clear surplus of the humus balance.

On farm level there is general trend to reduce livestock to 1.2 – 1.5 livestock or manure units ha^{-1}. Farms keeping livestock with a good humus equipment and a corresponding livestock number of > 1,5 GVE ha^{-1} would not need external organic amendments such as sewage sludge and compost.

As a principle in the judgement of nutrients a sufficient margin should be given for the compost fertilisation in order to allow for well designed humus reproduction and soil melioration even if in the short run positive nurtient balances might arise. Of course this should be accompanied by soil analyses.

3.4.2 Substitution potential of plant nutrients

On account of the plant nutrients contained in compost and digestion products corresponding quantities of mineral fertilisers can be substituted. Reliable analytical data for composts are available. According to that a substitution potential in Germany lies at 8 – 10%. Similar or even higher values can be assumed for Austria.

TABLE 3-19: SUBSTITUTION POTENTIA FOR PLANT NUTRIENTS BY COMPOST UTILISATION IN GERMANY (BGK E.V., 2005)

Fertiliser 1)	Nutrients in mineral fertilisers 1)	Nutrient quantities in compost 2)	Substitution potential %
Phosphate fertiliser (P_2O_5)	280.000 Mg	28.000	10 %
Potassium fertiliser (K_2O)	490.000 Mg	43.000	9 %
Lime fertiliser (CaO)	2.100.000 Mg	175.000	8 %

1) Plant nutrients from mineral fertilisers applied in Germany (Statistisches Bundesamt Wiesbaden, 2004[FA222])

2) Amount of plant nutrients per year in composts from separate collection of biowaste

According to an inquiry by Amlinger (2006[FA223]) a collection potential of biowaste of 115 Mt can be assumed Europe-wide and a compost production of approximately 50 Mt. This results in the following Europe-wide substitution potential for nutrients from synthetically produced mineral fertilisers.

TABLE 3-20: SUBSTITUTION POTENTIAL FOR NUTRIENTS FROM SYNTHETICALLY PRODUCED MINERAL FERTILISERS BY COMPOST UTILISATION AT EXPLOITATION OF THE UTILISATION POTENTIAL IN EU25.

Biowaste potential (Mg)		115.000.000	
Compost production (Mg))		50.000.000	
	N	**P_2O_5**	**K_2O**
Nutrients in compost (Kg Mg^{-1} f.m.)	10	6	12
Substitution of nutrients from mineral fertilisers (Mg)	**500.000**	**292.500**	**585.000**

Related to the supply with *trace elements* and *micronutrients* the test results can be summarized as follows

- As a rule inputs from compost don't have any measurable effects on the total contents of trace elements in soils
- An increase of the plant uptake of Cu, Mn, Zn can be observed in compost amended systems
- In any case composts are a valuable multi-nutrient source for soils with a lack of trace elements

3.4.3 Conclusions from the symposium

The papers presented at the symposium (Amlinger et al., 2003c) confirmed that with an average compost application sufficient amounts of macro nutrients are applied, however, the contents and the nutrient effect are fluctuating considerably with the used source materials and soil conditions. Furthermore compost creates a favourable environment for root growth and the active nutrient absorption through exchanging processes.

A long term compost management leads to an increase of the total and available contents of *phosphorus and potassium* in soils. Contrary to nitrogen (see Amlinger et al., 2003[FA224]) the direct effect of fertilisation of the total P, K and Mg input with compost is distinctly higher (> 20 – 70 %). Despite of that plant availability of phosphorus stays lower during the first years of compost fertilisation than with mineral P-fertilisers. Some tests even proved the phenomenon of a low additional P and K uptake from compost by the plant (< 10%) at a simultaneous increase of available P and K fractions in the soil.

Nevertheless it was suggested to consider the entire load of P and K when computing fertiliser balances in the course of a crop rotation.

For *sulphur* a short-term availability – similar to nitrogen – of 5 – 10% of the total sulphur input was stipulated.

A further remark was that an inappropriate application could lead to an excessive supply mainly of P and K. On a national level compost can cover a nutrient demand between 8 and 10% in agriculture if the collection and production potentials are utilised.

Interesting is the result of a Swiss survey where 50% of the consulted farmers evaluated compost above all because of its humic effect besides the positively assessed nutrient supply.

In all, the nitrogen value was classified to be low, what would make an additional nitrogen source necessary (farm manure, mineral N-fertiliser).

3.4.4 Plant nutrition by compost application: macro and trace elements – tabular survey

TABLE 3-21: PLANT NUTRITION BY COMPOST APPLICATION: MACRO AND TRACE ELEMENTS – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Bohne et al., 1996[SP225]	deep, decalcified lessivé from loess over terracegravel, tree nursery, Acer pseudoplatanus	BWC 785 dt ha^{-1}, 3000 dt ha^{-1}, horse manure 535 dt ha^{-1}	P- and K-content of soils increased especially with high Comp application rates (P by 6,09 mg/100 g soil).	P and K ↑
Boisch, 1997[SP226]	Field trial, (1991 – 1994),: 6 sites: sandy brown soil (konv., Sil-M; LM_C, N / P min. as initiationdose; pseudogley-gley, pseudogley-lessivé (konv. Ra – W-W – W-W); c) gley-pseudogley (Ra – W-Bar – W-Bar, mineral) d) sandy ground moraine, sandy brown soil (ecolog. Pot-R-O-SW).	BWC: 6 to16t d.m. ha^{-1}, according to demand, resp. 32 Mg d.m. ha^{-1} as ameliorationfertilisation on the light sites, reference site (ecolog. resp. non fertilized plots);	Nutrient-load from Comp no influence on the soluble content of P, K and Mg. Total nutrient application of P, K, and Mg from Comp contribute clearly to plant nutrition. Ameliorative fertilisation increases availability levels of P and Mg. Available nutrient contents were raised in comparison to non-fertilzed control, no differences between conventionally and Comp-plots. Nutrient leaching was detected only with K. Comp applications every few years as a reserve fertilisation is a possibility for argillaceous and loamy soils, sandy soils should be fertilized annually.	available P- , K- und Mg-concentration in soil ↑
Buchgraber, 2000[SP227]	6 field trials, on various sites, 1994 – 1998; M, W-W, W-Bar, S-Bar, Pu, Ra, IC; 1 trial random. block, 6 replic.; pasture	BWC 7,5 – 20 Mg ha^{-1}; MC 10-25 Mg ha^{-1}, with M and Ra 54 Kg ha^{-1} min. N – suppl. , granulated BWC	P, K and Mg in soils after 5 year BWC-fertilisation increased.	P, K und Mg im Boden ↑
Businelli et al., 1996[SP228]	Field trial, 6 years, M monoculture; random. block; 4 replications; argillaceous loam, pH 8,3; Corg 0,76%,	MWC, 25 – 30 cm incorporated, 1) 30 and 90 Mg f.m. ha^{-1} and year 2) 30 Mg ha^{-1} each during 1. and 4. year min., NPK-supplementation 3)control: NPK without Comp	*Statical significant* increase of available P and exchangeable K.	P, K im Boden ↑
Cortellini et al., 1996[SP229]	Field trial, 6 years, silty loam, CR: W-W, IC, M; Sil-M in plants and soil, OM, Ntot and available P in Boden	SSC + St, liquid and concentrated anaerobically treated Slu (7,5 and 15 Mg d.m. ha^{-1} and year); NPK	After 6 years increase in SOM, Ntot, available P, extractable Zn and Ni according to application rate.	
Cuevas et al., 2000[SP230]	Field trial, thin vegetation cover, degraded, semiarid soil, randomised block, 4 replications, soil analysis 1 year after compost application	BWC 0, 40, 80, 120 Mg ha^{-1},	Significant increase of anorganic N, P, K, conductivity, no significant increase of Corg, Ntot, CEC and pH. Increase of all all HM-concentrations, significant only with Zn, Pb and Cu with medium and high application rates.	

Authors	Experimental Design	Fertilisation	Results	Remarks
Delschen et al., 1996[SP231]	Theoretically demanded limitation of nutrientinput with landscaping and recultivation			
Gagnon & Simard, 1999[SP232]	Incubationexperiment; 23 agricultural Comp, 6 industrial Comp,	application rates equivalent to c. 35 –40 Mg f.m. Comp.	Except for SSC all industrial Comp showed similar N and/or P supply similar to most agricultural Comp. Materials with high P and OM and low C/P supplied more N and P to P-deficient soils. Netbalance for N and P negative for almost all materials.	
Hartl et al. (1999[SP233])	STIKO-trial: latin rectangle with 6 replications. CR: W-R, Pot, W-W, O, Sp, new Pot	BWC 12,5, 22,5 and 32,3 Mg f.m. ha^{-1}/year, averaged on trial years.	Increase in total-K and plant available K. No significant increase in total-P, sign. increase in plantavailable P with high Comp application rates; low application rates → no difference to min. variations; influence of Comp fertilisation within the top 30 cm, below (up to 1,5 m) no influence	P and K ↑
Hartl et al., 2003[SP234]	Continuation STIKO-trial: CR: W-R, Pot, W-W, O, Sp, new Pot	BWC: 11, 19 & 28 Mg f.m. ha^{-1}/year averaged on 8 trial years min. fertile.: 27, 44, 62 Kg N ha^{-1} + 39 Kg ha^{-1} P_2O_5 + 71 Kg ha^{-1} K_2O	Availability of P from Comp similar to superphosphate or tripplephosphate; Comp use positive for Cd-content of crops	
Maher, 1994[SP235]	vesseltrial, greenhouse, 5 months, argillaceous loam, ryegrass, Nst., EC, yield, leaching	SMC, 0, 25, 50, 100, 200, 400 Mg ha^{-1}	Major effect on EC. Increase of SOM and P, K and Mg-content of soils, but not on NO3-N. As P- and K-source: not much positive effect above 5 %; as N-source: increase in yield up to 25 % SMC.	
Martins & Kowald, 1988[SP236]	lessivé, uL; CR: SW, O, W-W, SW; 1976 - 1984 compostapplication biannually	6 variations, control, 40, 80, 120 Mg MWC without, 40, 120 Mg with min. fertilisation	During the first trial period (81 – 84) the amounts of plantavailable P increased on all Comp variations, in comparison to min. fertilisation, later immobilization. 1981 clear differences in K-content, contrary to P major seasonal fluctuations.	
Pfundtner & Dersch, 2001 [SP237]	veseltrial, 1997 : Pot, ryegrass ; 1998 : spinach, Pot	soil/quartz sand substrate 1 :1 ; 4 BWC, 2 Slu, P- and K-fertilizer, control	P: Sign. yield-increase in comparison to conrtrol; stronger effect of Comp than that of Slu on P-availability, utilization rate of Comp from 37 – 88 % (compare min. fertilizers). K: Sign. yield-increase in comparison to control, 2 Comp achieved yield levels of min. fertilisation . Recovery rate of 54 – 95 %.	
Pinamonti, 1998[SP238]	Field trial, 6 yeary, vineyard, calcareous soil, 15 % slope	control, PE(Polyethylen-mulch), 2 Comp (Slu+bark; MSW)	Both Comp increased the amount of available P and exchangeable K in the soil	P and K ↑

Authors	Experimental Design	Fertilisation	Results	Remarks
1998[SP238]	calcareous soil, 15 % slope, semysandy, gravel	Comp (Slu+bark; MSW)	exchangeable K in the soil.	
Tagmann et al., 2001[SP239]	Longterm field trial since 1978; comparison bio-dynamic (D), organic (O) conventional (K) and mineral (M) cultivation (DOK-trial) random. block; 3 plots (3 crops parallel; 4 replications. 4 cultivation systems, 2 fertilisation levels (96 plots) lessivé on loess CR: Kam, W-W, BR, W-W, Bar, 2x ley; soil samples 0-20 and 30-50 cm of N (control), D2, O2 (organic) and M2, K2 (convent.)	Supply of org. substance during 7 years (2. CR-period): (D1): 1010 Kg ha^{-1}; (D2): 2.020 Kg ha^{-1} in form of MC_C (O1) & (O2): RotM; (K1) & (K2): StabM ca. 1.000 resp. 2.000 Kg ha^{-1} each	P_{tot} and plantavailable P (1 minute isotopically exchangeable) after 21 trial years: medium P-supply through fertilizers (except in K2) less than P-extraction through crop, → mostly negative mean P-balance (N: 21, D2: -8, O2: -6, M2: -5, K2: +4): 1977 – 1998: topsoil: mean P-loss of 5,5 to 10,9 Kg P ha^{-1}/year, subsoil: increase of P-content from 7,0 – 8,7 Kg P ha^{-1}/year. Decrease in plant-available P-content from 12 mg P/Kg soil at trial-start until 1998 to11 in K2, 8 in M2, m6 in O2, 5 in D2 and 2 in N.	
Timmermann et al., 2003[SP240]	Long-term comost trial (8 resp. 5 year): duofactorial split-plot facility with 12 variations at 4 replications. random. → 48 plots per experiment 6 sites : lS, uL, uL, utL, uL, sL CR: M – W-W – W-Bar	Comp application: 0; 5; 10; 20 Mg ha^{-1}; N-supplementation level N0: no additional N-application level N1: 50 % of the optimal N-application level N2: 100 % of the optimal N- application on basis of the Nmin-content of the soil as well as further aspects, like preliminary crop etc. (comp. Nitrate information service - NIS).	Increase in mean of experiments with staggered Comp application rates (K1, K2 and K3) in comparison to K0: • P: 1, 4 and 8 mg P_2O_5/100 g (base value without Comp16 mg P_2O_5/100 g) • K: 3, 7 and 12 mg K_2O/100 g (base value without Comp 21 mg K_2O/100 g)	
Bartl et al., 1999[SP241]	STIKO since 1992, CR: O, Sp, Pot 1996 - 98	Highest mineral fertilisation, highest BWC-variation, 0	After 6 years no lack of trace elements on control, but increase in uptake of Cu, Mn, Zn caused by nutrient supply	
He et al., 2000[SP242]	Field trial, incubatioexperiment, sandy soil, analysis after 0, 240 and 360 days	SSC, farmwastes (green waste, shredded wood) , West Palm Beach CoComp (= combination);	Availability of N, P and K raised, also a few micronutrients like Fe, Cu, Zn and Mn. Microbial biomass-C and -P clearly increased. SSC produced less biomass-C than the Comp, inspite of high C- and nutrient-content.	

3.5 Enhancing buffer capacity, cat ion exchange capacity (CEC) and pH

3.5.1 Introduction

Soil organic matter (SOM) is a very important component of pH buffering in all surface soils, even those that contain relatively little SOM. SOM contains carboxyl and phenolic groups that can donate protons. Most of the acidity in SOM is contributed by the humified components, humic and fulvic acids. These acids can bind Al3+ ions, altering the proton donation behaviour of SOM.

SOM buffers pH over a wider range of pH values than might be predicted from a simple mixture of the two basic components of SOM benzoic acid and phenol. Results from laboratory analysis have shown the ability to buffer over a very wide pH range, suggesting a very diverse chemical composition of the functional groups. It has been suggested that this ability to buffer over a wide range of pH conditions may occur because of substitution within the humic acids. There are also negative charges produced by ionisation of the acid site. These negative charges bind exchangeable cations. Organic matter in soils is a major contributor to the variable charge shown by most soils.

SOM provides much of the pH buffering in surface soils. It has been shown for 60 mineral soils from Wisconsin that the mean cation exchange capacity of the soil organic matter was 200 cmolc Kg^{-1} (Helling et al., 1964[SP243]). This provides a reasonable estimate of the capacity of SOM to buffer pH in the range of 3 to 8 within which the vast majority of temperate soils are found.

Addition of organic matter to soil may result in increases or decreases in soil pH, depending on the influence the addition has on the balance of the various processes that consume and release protons. The factors which need to be considered include the chemical nature of the soils and that of the organic material added as well as environmental properties including water content and extent of leaching.

The net effect of adding organic matter to acidic soils is generally an increase in pH. The main processes leading to this increase are:

- a de-complexation of metal cations
- mineralisation of organic N
- denitrification

the net effect of adding organic matter to alkaline soils tends to acidify them especially under waterlogged and leaching conditions. The main processes are:

- mineralisation of organic S
- mineralisation followed by nitrification of N
- leaching of the mineralised and nitrified organic N
- dissociation of organic ligands
- dissociation of CO2 during decomposition

An essential utilisation effect of compost fertilisation is the supply of so-called *alkaline effective materials*, mainly in form of calcium carbonate.

According to Timmermann et al. (2003[SP244]) lime supply by compost has a dimension of preservation liming. This can be looked upon as a saving potential of other lime sources. In correspondence with Ebertseder (1997[SP245]), Pissarek & Pralle (2001[SP246]) und Buchgraber (2002[SP247]) this at least stabilises respectively often even increases the pH values of the soil.

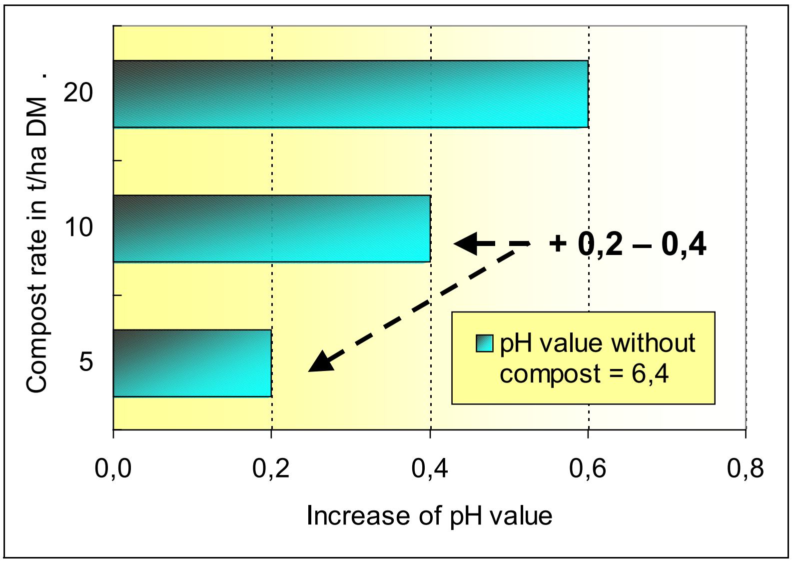


FIGURE 3-13: MEAN VARIATION OF THE PH VALUE IN DIFFERENT SOILS AFTER 8 – 11 YEARS OF COMPOST APPLICATION (KLUGE, 2006)

After further 3 years of the above mentioned trial (Timmermann et al., 2003) on several locations Kluge (2006) confirmed a significant increase of the pH value even at moderate compost applications. A mean increase of the pH value of 6.4 to 6.8 at 10 Mg d.m. compost $ha^{-1}a^{-1}$ appeared. (Figure 3-13). Thus a supply of annually 200 – 400 Kg CaO ha^{-1} at compost applications between 6 and 7 Mg d.m. ha^{-1} corresponds to a *preservation or maintenance liming* and stabilisation of the pH value.

In a ten years field trial with vegetables (beans, broccoli, carrot, onions, chilli, tomatoes) Warman (2003) stipulated an increase of the pH value with applied compost quantities between 13 and 63 Mg f.m. $ha^{-1}a^{-1}$ what, however, was not statistically significant. Contrary to the mineral fertilisation plots in the compost amended soils there was a distinct increase of the cation exchange capacity (CEC; + 1,5 cmol Kg^{-1}) and the Ca concentration (increase of the Mehlich-3 extractable Ca by 15-30%)

The results can be summarised in the following statements

- Regular compost application keeps the pH value of the soil respectively in most cases steadily increased; there are only rare papers where a lowering of the pH value is reported
- Lime supply through a regular compost application corresponds to at least a *preservation liming* even at amounts less than 10 Mg TM $ha^{-1}a^{-1}$
- The theoretically assumed increase of the cation exchange capacity compared to treatments without compost is confirmed in the evaluated literature.

3.5.2 Compost effect on pH and CEC – tabular survey

TABLE 3-22: COMPOST EFFECT ON PH AND CEC – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Effects on pH and CEC				
Boisch, 1997[SP248]	Field trial, (1991 – 1994),: 6 trialplots: sandy brown soil (konv., Sil-M; LMc, N / P min as initiation dose; pseudogley-gley, pseudogley-lessivé (CR: conv. Ra – W-W – W-W); c) gley-pseudogley (Ra – W-Bar – W-Bar, mineral) d) sandy ground moraine, sandy brown soil (CR: ecolog. Pot – S-R – O – SW).	BWC: 6 to16t d.m. ha^{-1}, according to demand, resp. 32 Mg d.m. ha^{-1} as amelioration fertilisation on the same sites, control (ecolog. plots non fertilized);	No effect on soil-pH, SOM, CEC. Increase in salinity directly after application, detectable in leachate., but not any more after ½ year. Comp applications every few years as a reserve fertilisation is a possibility for argillaceous and loamy soils, sandy soils should be fertilized annually.	No effects on pH, CEC, SOM
Diez & Krauss, 1997[SP249]	Field trial, 20 years, 2 sites: CR: SB – W-W – S-Bar sandy loam, CR: Pot – W-W – S-Bar loessloam; no information on statistics	MWC, year 1 – 12: every 3rd year 40 – 45 Mg d.m. ha^{-1}, year 13 – 20: annually 15 Mg d.m. ha^{-1}, with & without min. NPK-supplem.; control: without fertilisation and NPK no Comp	Increase in pH-value gravel-loam-soil: 6,7 → 7,3; loess-loam-soil: 6,6 → 7,3	pH ↑
Eghball, 1999[SP250]	Field trial, start 1992, random. block, 4 replications, M, silty, argillaceous loam, pH 6,2,	f.m. resp.annual resp. biannual application accoring to N- and P-demand of M (151 Kg N ha^{-1}, 26 Kg P ha^{-1}), 368 to 1.732 Kg $CaCO_3$ ha^{-1} on demand min. N-supplementation, NPK	Topsoil sample ($0^{-1}5$ cm) from 1996; NPK: pH drops from 6,2 to 5,6; StabM- and Comp application keep the original pH, N-based fertilisation raised the pH-value more than control and P-based fertilisation. Significant correlation between pH and $CaCO_3$-content of manure and MC.	
Kahle & Belau, 1998[SP251]	Mitscherlichvessel with field trial (semiloamy sand), incubationexperiment (slightly loamy sand); annual reygrass	vessel: BAK 10, 20, 40, 80, 100 Mg ha^{-1} f.m.	Raised Corg- and Ntot-content, linear increase of the CEC, maximum increase almost 10% of the potential CEC. Increase of base saturation, the sorbed CA- and K-content and pH. No change in SOM contents. Increase in TOC-content and chloride content. NO_3-content varies clearly in dependency of N. Soil density decreases. 70% of org. matter of the BWC proved to be stable in incubation test with a balanced N mineralization-immobilization pattern.	CEC and pH ↑

Authors	Experimental Design	Fertilisation	Results	Remarks
Kögel-Knabner et al., 1996[SP252]	incubationexperiment, 18 months, lessivé, brown soil	2 BWC different rotting degrees	Short- and long-term increase of pH and CEC	pH and CEC ↑
Madejón et al., 2001[SP253]	Field trial, 2 years, random. block, 4 replications., M, SB, SF; calcareous, loamy sandy soil	3 different subarbeeet-Vinasse-Co-Compo, 1st year: 15 Mg ha^{-1}, 35 Mg ha^{-1}, 7,5 Mg ha^{-1} ,2nd year: 14, 22 and 14 Mg ha^{-1} plus 600 Kg NPK; 3rd year aftereffects, NPK (1000 Kg ha^{-1} N^{-1}5 $P_2O_5$$^{-1}$5 K_2O), 0; 300 Kg urea (except 0-plot);	Soil:no effect on pH; slight increase of salinity, SOM-content increased sign. through Comp application, in most cases, same trend with average C-content of humic extraction; continuous sign. increase of the humic-acid-fraction. CEC-increase after 2nd crop, decrease after 3rd crop, each higher than in control and min. variation. At the end of the 1st trial period N (Kjehldahl) of Comp plots higher than min. and control, partially significant. P-content in all variations similar.	
Martins & Kowald, 1988[SP254]	since 1976, lessivé, uL,	MC 40, 80, 120 Mg TS with and without NPK; every 2 years, 25 cm incorporation	On Comp-plots pH-value increase after 2 applications.	pH ↑
Ouédraogo et al., 2001[SP255]	2 fieldtrials in Burkina Faso, random. block, 4 replications., Sorghum bicolor with seedingdelay; loamy sand (0-20 cm) resp. sandy-argillaceous loam (40 cm);	BWC, f.m., plant residue and ash, composted during rainy season, 0 and 10 Mg ha^{-1} resp. 0 and 5 Mg ha^{-1}.	Soil color: slightly brownish grey (0) → brown (5 and 10 Mg ha^{-1}); soil consistency hard (0) resp. crumbly (5,10); clear differences in colonization through fauna and rooting. During bloom and 3 months after harvest: no sign. differences in Corg-content. All Comp fertilized plots pH and CEC increase. At the time of harvest raised nutrient content in the soil dependent on application rate. Increase in yield 45% (5t ha^{-1}), sign. 3-fold increase at 10 Mg ha^{-1} application. No yield recuction on Com fetilized plots, despite seeding delay of 1 month.	
Timmermann et al., 2003[SP256]	Longterm compost trial (8 bzw. 5 Jahre): duofactorial split-plot facility with 12 variations at 4 replications. random. → 48 plots per experiment 6 sites : lS, uL, uL, utL, uL, sL CR: M – W-W – W-Bar	Comp application: 0; 5; 10; 20 Mg ha^{-1} N-supplementation level N0: no additional N-application level N1: 50 % of the optimal N-application level N2: 100 % of the optimal N- application on basis of the Nmin-content of the soil as well	The Comp applications at the least maintained soil pH-value, but mostly raised it gradually (starting at a mean base pH-value of 6,1 without Comp - every application step effected an increase of = 0,2 pH units. Raise of 0,4 pH-units through annual Comp applications of 10t ha^{-1} d.m..	

Authors	Experimental Design	Fertilisation	Results	Remarks
		as further aspects, like preliminary crop etc. (comp. nitrateinformationsservice - NIS).		
Wong et al., 1998[SP257]	incubation, 14 days, 3 tropical soils: spodosol (Sumatra), oxisol (Burundi), utisol (Cameroon)	4 composts : GWC, MWC, MC; 1,5 % w/w	pH-raise directly proportional to proton absorption capacity of the OM. The proton absorption capacity ist a precise measurement unit for the capacity of Comp to raise pH-value and to reduce the Al-saturation.	
Stamatiadis et al., 1999[SP258]	Field trial, silty argillaceous loam, broccoli	Comp (origin unknown) 0, 22, 44 Mg ha^{-1}, NPK 165 Kg N ha^{-1}	Benefits of Comp: rise and stabilization of pH-value, decrease of the water-infiltration-rate. The stabilization of the pH-value prevents an acidification of the soil, in case of NPK-application.	pH ↑ and stabiliziert
Zinati et al., 2001[SP259]	Field trial since 1996, calcareous soil with 67 % gravelfraction (>2mm); vegetables	BWC (100 %), Bedminster CoComp (75% BAK and 25% SSC) and SSC (100%); application 1996 and 1998, 72, 82,7 and 15,5 Mg ha^{-1} d.m., = 168 Kg N ha^{-1}*a; control 0 and NPK;	19 months after application: significant lowering of the pH-value, increase of conductivity.	pH ↓

3.6 *Compost and soil physical properties*

3.6.1 Soil physical parameters - a short introduction

3.6.1.1 Soil structure, Aggregate stability

Soil structure is a physical parameter, including size and spatial distribution of particles, aggregates and pores in soils. A structure to be achieved by a corresponding soil management is featured above all to support plant growth and minimise erosion. Central components of the soil structure are soil aggregates in a size ranging from 1 to 10 mm, staying stable even at humidification (Piccolo, 1996[SP260]). Various authors (Oades & Waters, 1991[SP261]; Tisdall & Oades, 1982[SP262]; Piccolo, 1996[SP263]; Golchin et al., 1998[SP264]) postulate a so-called aggregate hierarchy with three levels:

(1) Micro aggregates: < 20 µm = packages of flocculated clay plates,

(2) Micro aggregates: 20 – 250 µm = stabile aggregated packages of clay plates,

(3) Macro aggregates: > 250 µm = aggregated micro aggregates

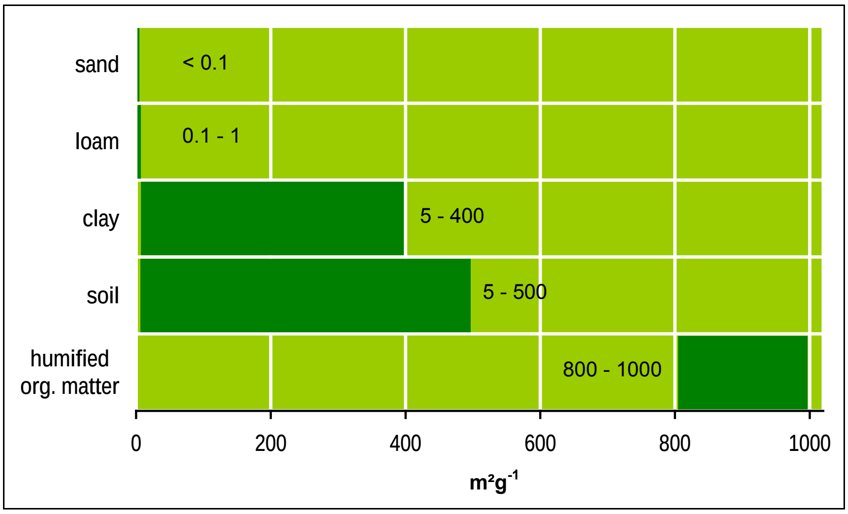


FIGURE 3-14: SPECIFIC SZRFACE OF SOILS AND HUMIFIED ORGANIC MATTER (BGK E.V., 2005; SCHFFER & SCHACHTSCHABEL, 1998)

An essential factor of the aggregate and pore properties of a soil depends on the *specific surface* connected with these properties. On these surfaces of the macro to the micro scale the storage and exchange processes of water and substances between soil fauna, microorganisms and root hairs take place. These “active” surfaces ideally covered by a water film are the habitat of microorganisms, which on the other hand create the pre-requisite for an optimum soil formation.

According to the prevailing debate among experts the aggregation and thus the soil structure can be distinctly declined by a considerable SOM-degradation (e.g. as a consequence of a corresponding soil management). This judgement needs, however, a closer look on aggregation processes on different scales (micro and macro aggregates) and under consideration of the different SOM-fractions and their transformation rates.

Starting point for the aggregate formation and stabilisation on the first hierarchy level is the clay mineral floccation, which is supported by the presence of SOM, but can also be observed between “naked” clay mineral plates. These flocculated small particles (mostly < 2 µm) according to Tisdall & Oades (1982[SP265]) are connected and stabilised through inert organic aromatic materials, connected and stabilised by polyvalent cation bridges (complexes) with silicates (clay minerals) to aggregates in sizes of 2-20 µm. A further mechanism of micro aggregation arises from bacteria colonies or fungi hyphen surrounded by a clothing of carbohydrates (polysaccharide) and adherent clay particles. This structure remains after the organisms died off, as the dead bacteria are protected from degradation by the clothing with clay. In this case one speaks of an inert organic matter which is not stabilised by the process of humification and cannot be influenced directly by fertilisation.

Micro-aggregates in the range of 20-250 µm are also stabilised by inert humified SOM besides oxides and clay minerals. A further role play temporarily living and convertible dead SOM (fine roots and hyphen networks glue like Polysaccharide, which are root and microbial exudates; Piccolo, 1996[SP266]; Baldock & Nelson, 1999[SP267]). Soil cultivation affects mainly *macro-aggregates*. These are stabilised by a fine network of roots and fungi hyphen but also by plant residues and added organic material. (Piccolo, 1996[SP268]; Baldock & Nelson, 1999[SP269]).

Frequently, there is nor clear evidence for a relation between aggregate stability and SOM content. In fact the portion of individual SOM fractions influencing the aggregates of the different hierarchy levels must be considered. Hereby a “periodical” hierarchy for SOM may be important. *Macro-aggregates* are stabilised above all by living respectively lately died off biomass (fungi hyphen, fine roots, root hair, microorganisms) with a high portion of easily degradable polysaccharide, showing high transformation rates and short transformation periods (few days up to some months). Stronger degraded organic groups are increasingly responsible for the stabilisation of *smaller aggregates*, the transformation periods of which can lie between some years and several thousand years (Carter, 1996[SP270]; Elliot et al., 1996[SP271]; Tisdall, 1996[SP272])

The resilience of soil aggregates against destruction and being dispersed (aggregate stability) is decisive for the maintenance of the pore systems of soils. The stability of aggregates results primarily from clay-metal-SOM-complexes. Besides this experimental results have discovered the formation of additional intermolecular links between SOM components. Soils with low Al and Fe oxides and high SOM contents showed these effects increasingly following desiccation (Haynes, 1993[SP273]). Primarily the *hydrophoby* of aggregates after desiccation and the herein contained organic matter respectively was discussed for being a key pre-requisite for stability as well as for the erosion resilience of soils. The hydrophobing of aggregates decelerates the infiltration of water and reduces the aggregate deterioration which is especially advanced by rapid penetration of water by enclosed air (air explosion) (Zhang & Hartge, 1992). Most effective are organic substances with numerous methyle and methylene groups. According to Piccolo & Mbagwu (1989[SP274]) the content of these materials in soil can be promoted by cultivation measures, i.e. cultivation of cultures producing water-resistant humified organic substances or by application of hydrophobic organic substances. How this could be achieved in practice and if e.g. mature composts are to be preferred under this aspect couldn’t be gathered from the viewed literature.

Besides the hydrophobic components the carbohydrates proved to have an aggregate stabilising effect, too. The substantiated stability of artificial aggregates after adding e.g. glucose, didn’t last, as glucose can rapidly be degraded by microorganisms, whereby the degradation products may have an aggregate-stabilising effect.

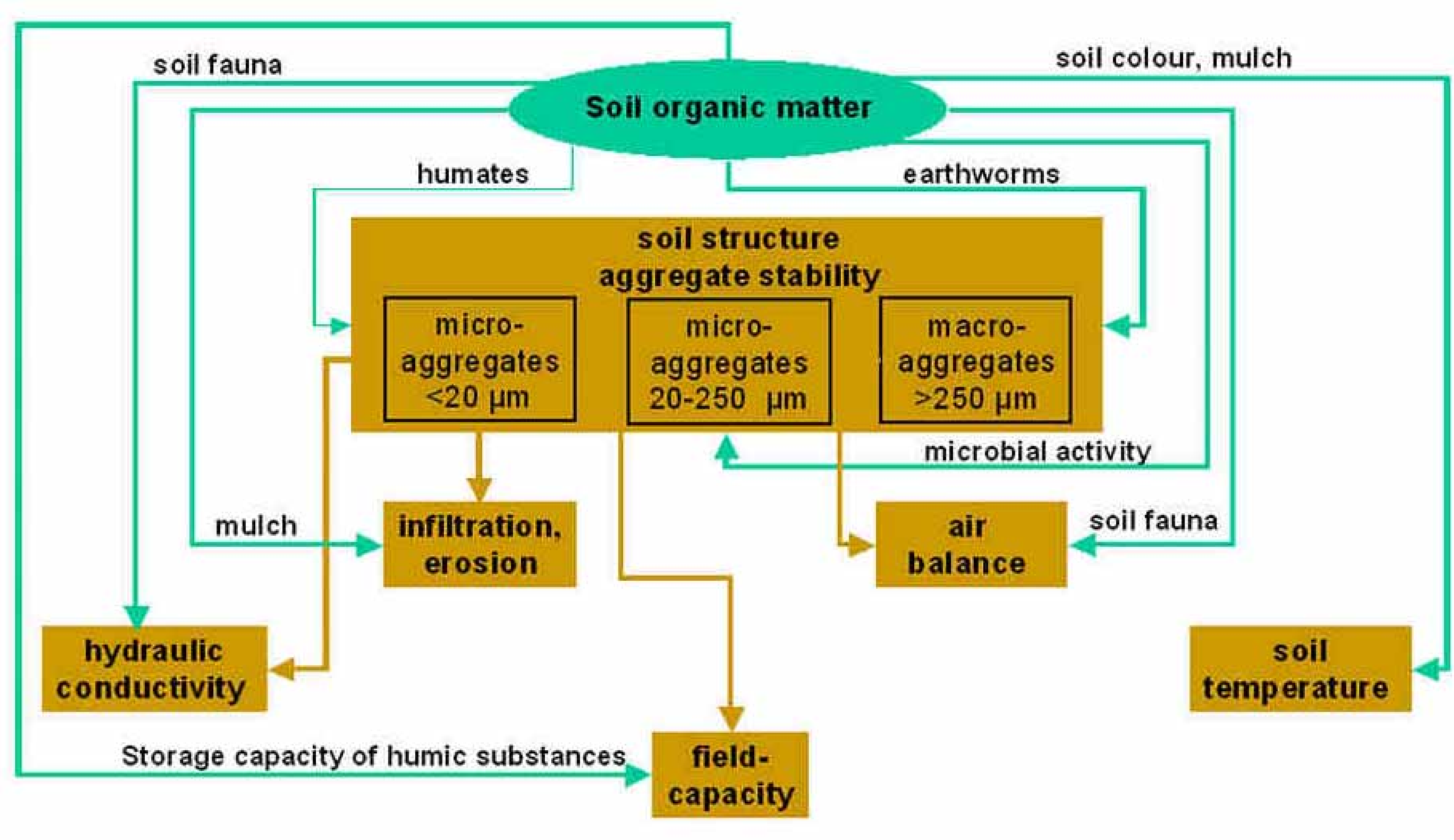


FIGURE 3-15: THE ROLEOF ORGANIC MATTER FOR SOIL PHYSICAL PROPERTIES

In summary it can be said, that except of soil temperature the soil structure and the aggregate stability are the most important influencing factors on the observed soil-physical parameters. The influence of organic matter and the possibility to influence the soil-physical properties with the application of organic amendments must be assessed in dependence of the scale of aggregates. The first hierarchy level (micro-aggregates < 20 µm) seems to be a function of the clay content and inert SOM and cannot be influenced basically in a short or medium course by a certain soil management. The obvious question whether the clay content is exclusively important hereby has not been solved as well to what extent silt fractions, the clay and silt mineralogy and further parameters (exchange balance, pH value, humus quality) are essential for aggregating effects. The same factors are effective for the formation and stabilisation of micro-aggregates of 20 – 250 µm as for the smallest aggregates. In addition the influence of the plant population (root exudates) and the supply of organic fertiliser must be considered if this is carried out with higher molecular and extensively humified material (Piccolo, 1996[SP275]). The macro-aggregate formation is encouraged by the supply of organic materials, requires, however, the presence of micro-aggregates (< 250 µm) as components, the formation of which can only be influenced indirectly over the increased formation of bacteria colonies or fungi hyphen quasi as “aggregating germs”.

In total it can be concluded that the enlargement of the transformable SOM-pool can support the soil structure by the supply of exogenous organic matter above all in cohesive soils (clay) or in sandy soils. Hereby on the one hand well humified (micro-aggregates) but mainly fresh, low-molecular substances (macro-aggregates) can have a positive effect.

3.6.1.2 Hydraulic conductivity

Hydraulic conductivity means the percolation rate in soils per area and time unit. It is dependent on both the actual soil-moisture tension and the actual water content of the soil, but on the other hand also on the number, size and formation of the pores existing in the soil. The pore volume and the pore size distribution is a function of particle size. Generally it can be assumed that the pore volume and the portion of fine pores will accelerate with diminishing particle size, while the portion of macro pores will decrease. Besides these particle driven primary pores there is another group of secondary pores which is decisively determined in its number, size and form by the SOM. The secondary pores are mostly a matter of root and animal tubes which for the most part can be allocated to the macro pores (> 10 µm) and are often showing a distinct continuity. But also the soil structure and thus the aggregate stability contributes to the formation of secondary pores. *By these means incorporated organic matter improves the water conductivity by forming a nutrient basis for soil organisms and through a direct structure-stabilising effect.* Mainly in cohesive clay and silt soils the hydraulic conductivity can be increased distinctly. Well rooted top soils having a high number of macro-fauna the secondary pores are predominantly influencing the water conductivity, in the sub-soils this influence deteriorates on account of decreasing portions of SOM in favour of the primary pores.

3.6.1.3 Infiltration and erosion

Infiltration is the movement of leachate from the surface or above layers into the soil. Infiltration comes along with precipitation, irrigation and flooding. The course of infiltration is marked by the infiltration rate which indicates how much water per time unit is drained. The hydraulic conductivity of a soil is the measure for infiltration. As soon as the infiltration decreases by aggregate destruction (→ clogging of macro pores), silt-up and caking of the soil respectively, infiltration diminishes and surface run-off (erosion) increases at high water supply rates.

Among other components the aggregate degradation is promoted by swelling and air explosion. At air explosion the air in the aggregates is compressed by infiltrating water up to pressures of 6000 hPa. As a consequence the aggregates burst as soon as the cohesive power is surpassed. Zhang & Hartge (1992[SP276]) proved that air explosion and swelling has a far stronger effect the faster the water enters the aggregates.

The infiltration velocity is reduced by organic matter as it reduces the moistening of the aggregates. The efficacy of organic matter increases hereby with an increasing humification degree of the organic material.

The aggregate size plays also a role during degradation. The degradation rate of aggregates from 10-20 mm diameter decreases, because the ratio between the rain drop diameter and aggregate diameter decreases and thus reduces the humidification velocity (Freebairn et al., 1991[SP277]; Frielinghaus, 1988[SP278]). Larger aggregates reduce the surface run-off and the erosion further on through coarsening of the micro relief. This leads to an increase of the effective surface and to a reduction of drop impact energy per area unit.

Additionally a coarse micro relief causes the formation of cavities where arising surface water can be retained. By this the beginning surface run-off can be delayed and the tortuosity of the discharge channels increased. This leads to a reduced run-off velocity (Helming, 1992[SP279]; Kaemmerer, 2000[SP280])

The stability and size of the aggregates can be distinctly increased through cultivation measures combined with a supply of organic matter (direct and mulch drilling, cultivation of catch crops and undersown crops) (Kaemmerer, 2000[SP281]; Stott et al., 1999[SP282]). Organic matter applied as mulch does reduce erosion by covering of the soil surface, because it buffers the energy of the impinging rain drops and so only a part of the energy affects the soil aggregates.

3.6.1.4 Field capacity

Field capacity (FC) means the water amount which a soil can retain against gravity. Decisive here is the pore volume which characterises the portion of cavities existing in the soil and the pore size distribution as only pores below a pore diameter of 50 µm are responsible for the water storage. From the viewpoint of plant cultivation it is not the field capacity being the decisive parameter for water supply of the plants but the effective field capacity (FC_e) as plants can extract water from the soil only up to a certain soil moisture tension and pore size. Therefore the FC_e comprises only the pores with a diameter of 0.2 µm to 50 µm (meso and small macro pores).

FC or FC_e respectively is influenced by the particle size, the structure and the content of organic matter. The FC increases with decreasing particle size, as both the pore volume and the portion of meso and fine pores increases with a decreasing particle size. Therefore the FC_e achieves a maximum in silt soils, because there the portion of meso pores is at the highest, while fine pores are preponderant in clay soils the water of which cannot be used by the plants.

Via its impact on the secondary pores structure and organic matter have a strong influence on the field capacity (Baldock & Nelson, 1999[SP283]). Thus the effect of organic matter above all in soils with low portions of primary meso pores can be assessed positively. *The SOM increases the portion of meso pores through an improved aggregate formation and stabilisation in sand and clay soils.* Furthermore fungi hyphen and roots contribute to an increase of field capacity by formation of secondary meso and macro pores. The organic matter contains a high water storage capacity which also has a positive effect on the field capacity. *Humus is able to take up a three to fivefold of its own weight of water, humic materials up to a twentyfold of their own weight* (Hayes et al., 1989[SP284]; Scheffer & Schachtschabel et al., 1998[SP285]). According to Hudson (1994[SP286]) the FC_e of a soil is duplicated by — increase of the Corg-content of 0.5% to 3% (admittedly this is an extreme increase and would not be achievable through cultivating and fertilising measures)

3.6.1.5 Soil air

The composition of soil air is variable and partly deviates strongly from the composition of the atmosphere. As a rule it contains less oxygen and more CO_2. Furthermore it possesses increased contents of H_2S, methane and N_2O above all under reducing conditions (O_2-lack). Therefore good aeration of the soil is not so much beneficial for the soil biota but it avoids respectively reduces the emission of greenhouse gases like methane and N_2O (Dörr et al., 1992[SP287]; Flessa & Dörsch, 1995[SP288]; Granli und Bøckman, 1994[SP289]).

The air portion in the soil results from the difference between total pore volume and the pores filled with water. That means that the air supply of the soil is predominantly assured with the coarse particles > 50µm. As a rule sand soils have a proper aeration with a great portion of primary macro pores dependent on the particles, while clay soils on account of the low portion of macro pores may have problems with air supply. Thus the influence of the organic matter on the air supply is especially high in these soils as it contributes decisively to structure and structure stabilisation and thus stimulates the formation of secondary macro pores. Especially channels of roots and animals as a consequence of the supply of organic matter with their continuity have a positive effect on air supply.

3.6.1.6 Soil temperature

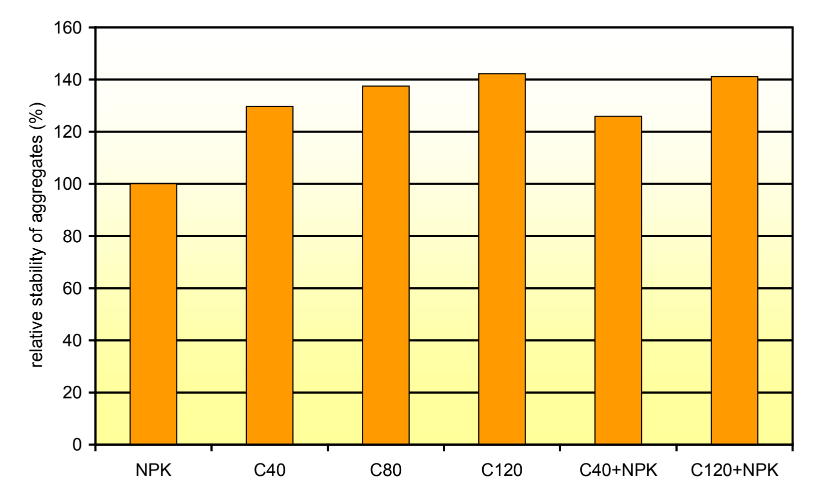
The soil temperature is predominantly viewed because of its influence on the velocity of chemical reactions, metabolism and growth processes of organisms. Temperature fluctuations arise daily and seasonally and are connected to the conditions of the atmosphere, but decrease with the depth in the soil. The organic matter is effective over the influence on the absorption capacity on the caloric household of a soil. Soils with high contents of organic matter are dark coloured on account of the dark colour of the humic substances and thus can absorb a higher radiation. In spring they warm-up faster than light-coloured soils. With a high portion of organic matter in soils (bog soils, lowland bog) increases the danger of night frosts. These soils absorb during the day a lot of radiation und warm-up quite strongly, however, the radiated energy is hardly passed in deeper layers, as the heat conductivity of organic matter is very low. During night a lot of energy is radiated and on account of a missing supply of heat from lower soil layers night frosts are possible. Organic layers (mulch) can reduce the soil temperature and smooth the fluctuations depending on day and seasonal times. So, Pinamonti (1998[SP290]) found higher soil temperatures in early summer and late fall below mulch layers, whereas in the middle of the summer he found lower soil temperatures in topsoil than in uncovered soils.

3.6.2 Effect of Compost on soil physical parameter – examples from literature

A positive influence of compost on soil physical parameters above all by influencing an aggregate stability (measured as "percolation resistance") can be expected. The effect of the organic matter created by compost can be attributed hereby to three important aggregate stabilising factors (Goldbach & Steffens, 2000[SP291], Scheffer & Schachtschabel et al., 1998[SP292]):

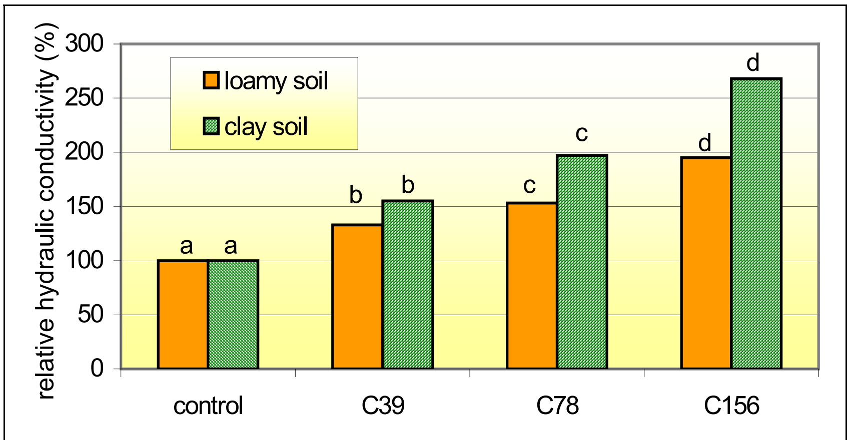
- The microbial activity is encouraged by the application of organic matter. This contributes to aggregate stability by the formation of interim products from microbial degradation and metabolic products of microorganisms with sealing properties. But this stabilisation has only a temporary effect, as with an increasing degradation of the easily transformable organic matter the microbial biomass deteriorates.
- The activity of earthworms is encouraged over the supply of organic matter. Their faecal aggregates do also have a positive effect on soil structure and are additionally influencing the air household by the formation of wide macro pores.
- A long-term aggregate stabilisation is caused over the supply of high-molecular humic material. The portion of which is higher in compost than in "fresh" organic matter, as these are formed by the transformation and degradation processes during composting.

The numerous researches about the influence of compost on soil-physical properties do not result in a homogenous picture. In fact the aggregate stability and further soil-physical properties do improve (see e.g. Martins & Kowald, 1988; Figure 3-16) when compost is applied in nearly all of the tests, however, a significant compost effect is not always the case. Investigations which stipulated a significant compost effect were carried out with high portions of compost which were higher than a practice-relevant application amount (z. B. Aggelides & Londra, 2000[SP293]; Buchmann, 1972[SP294]).



NPK: ONLY MINERAL FERTILIZER, C40 – C120: 40, 80, 120 MG HA^{-1}, C40/C120+NPK: COMPOST+MINERAL FERTILISER)

FIGURE 3-16: RELATIVE STABILITY OF AGGREGATES BY DIFFERENT AMOUNTS OF COMPOST APPLICATION (MARTINS & KOWALD, 1988[SP295])



control: no compost, C39-C156: amount of application in tons, different letters indicate significant statistic difference (p=0,05)

FIGURE 3-17: RELATIVE HYDRAULIC CONDUCTIVITY AT DIFFERENT AMOUNTS OF COMPOST APPLICATION IN TWO SOILS (AGGELIDES & LONDRA, 2000)

It can be concluded that composts mostly have a positive effect on soil-physical properties, but it is not finally clarified which influence the different organic components of the composts have on the aggregate stabilising processes in the soil and how far conditions of soils and location are influencing these effects (also see general relations in Figure 3-15)

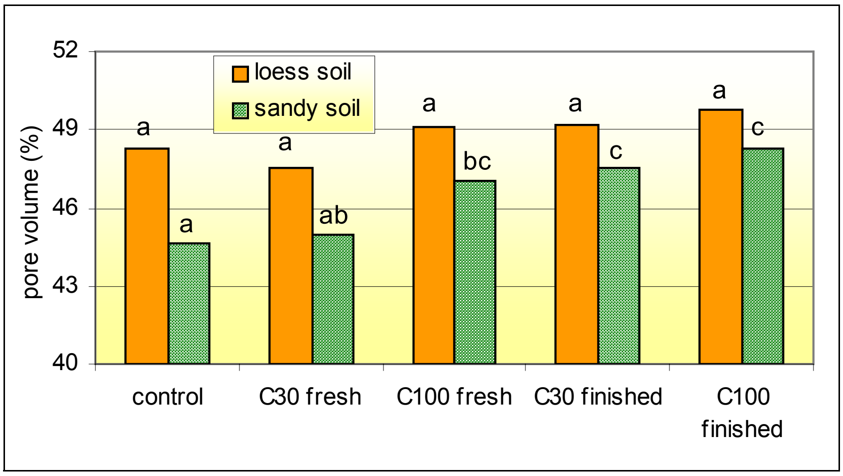
Aggelides & Londra (2000) e.g. found a significant increase of the hydraulic conductivity and the field capacity above all on clay soils, which have been fertilised with compost (Figure 3-17).

Distinct results can be expected only with long-term trials (at least 7 – 10 years) with a special attention on the experimental design and the homogeneity of the location.

Therefore some studies could not detect an influence on the soil-physical parameters (Asche et al., 1994).

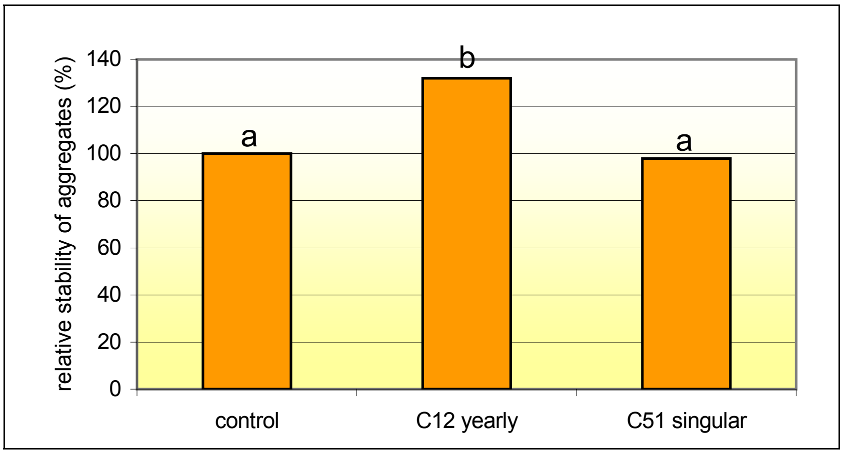
Besides the compost quantity the type of compost (fresh or mature compost), the intervals of application and above all the soils on which compost will be applied are influencing factors of the compost effect. The field trials of Petersen & Stöppler-Zimmer (1995[SP296]) showed better effects of mature composts on the aggregate stability and pore volume than fresh composts, whereby the improved effect on the pore volume could only be proven on sand soils ((Figure 3-18).

From the results of Lamp (1996) it can be supposed that a yearly application of small amounts is more effective on stabilisation of aggregates and the pore size distribution as the singular application of high amounts (Figure 3-19). The low effect of a compost fertilisation carried out every 3 years of 51 Mg d.m. ha^{-1} on the aggregate stability compared with an annual application of 12 Mg d.m. ha^{-1} is based on the low effect of the microbial incorporation and a too low amount of stabilising humic materials.



control: only mineral fertiliser, C30/C100 amount of application in tons, different letters indicate significant statistic difference (p=0,05)

FIGURE 3-18: PORE VOLUME AT DIFFERENT AMOUNTS AND TYPES OF COMPOST IN TWO SOILS (PETERSEN & STÖPPLER-ZIMMER, 1996)



control: only mineral fertiliser, C12/C51 amount of application in tons, different letters indicate significant statistic difference (p=0,05)

FIGURE 3-19: RELATIVE STABILITY OF AGGREGATES AT DIFFERENT AMOUNTS AND TYPES OF COMPOST APPLICATION (LAMP, 1996)

This conclusion is supported by Kögel-Knabner et al. (1996[SP297]) who researched humification processes after compost application. They found a strong increase of microbial biomass after application above all with fresh composts (high portion of easily degradable organic matter). After approx. 2 months the microbial mass decreased by 60-85 % and after one year reached the level of soils without compost application.

Strauss (2003) examined soil erosion and surface run-off from soils fertilised for over 7 years with compost and not fertilised plots (particle size distribution: sand: 17%; silt: 60%; clay: 23%) with a rain simulator.

Soil erosion in the compost plots was reduced by ca. 1/3 (Figure 3-20). The drain decreased from 25 mm to 12 – 18 mm. Increasing drain values result in increasing soil erosion. Soil erosion in the control plot starts earlier during irrigation and in higher rates. That indicates distinctly different hydraulic properties of the untreated soil. The compost fertilised soils distinguished themselves between the parameters of soild density, C_{org} and saturated hydraulic conductivity. The differences have been statistically significant (p=0,05).

The test also shows that the increasing humus content on account of compost application improves both soil structure (lower soil density) and – as an subsequent effect – soil erosion decrease. (Figure 3-21). This relation was also shown in other papers (Adams, 1973 [FA298]; Morgan, 1995[FA299]). These results indicate a slower compaction of soils with good SOM equipment during rainfall. Interesting is that the field trials shows distinctly better results regarding the actual soil erosion than this could be expected in a model calculation on basis of the given soil data.

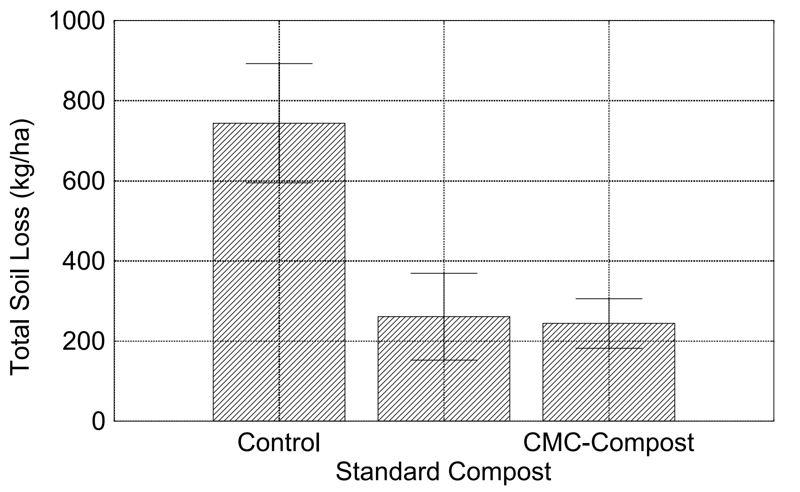


FIGURE 3-20: TOTAL SOIL LOSS (KG HA^{-1}) OF THE INVESTIGATED TREATMENTS. ADDITIONAL BARS INDICATE STANDARD DEVIATION (STRAUSS, 2003)

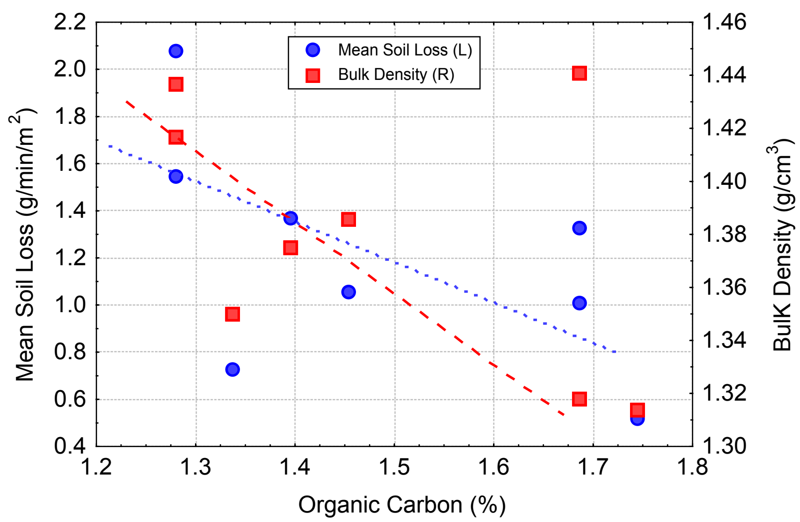


FIGURE 3-21: ORGANIC CARBON CONTENTS COMPARED TO MEAN SOIL LOSS AT CONSTANT RUNOFF RATES AND BULK DENSITY OF THE PLOTS (STRAUSS, 2003)

TABLE 3-23: MEAN PLOT VALUES FOR BULK DENSITY, SATURATED HYDRAULIC CONDUCTIVITY AND ORGANIC CARBON (STRAUSS, 2003)

Treatment	**bulk density (g/cm^3)**	**C_{org} (%)**	**hydraulic conductivity mm/h**
control	1.41	1.34	3.9
standard compost	1.35	1.63	6.9
CMC compost	1.38	1.69	5.9

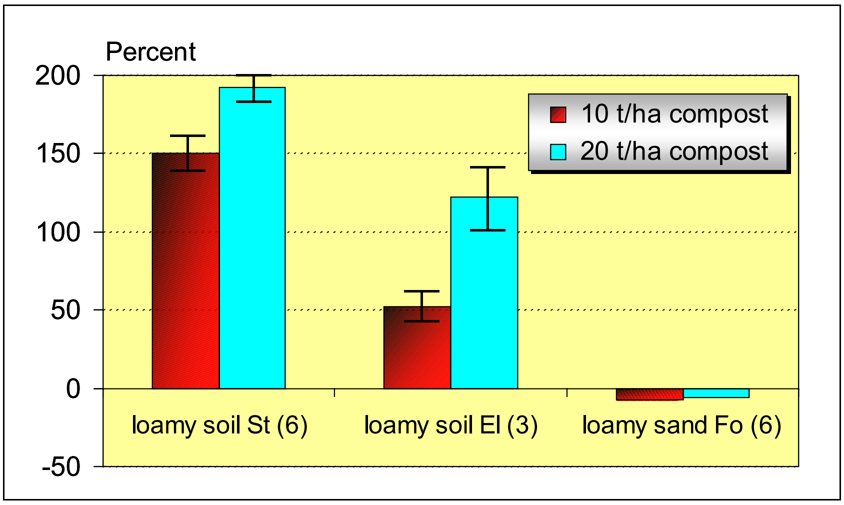


FIGURE 3-22: EFFECT OF COMPOST ON AGGREGATE STABILITY - RELATIVE INCREASE IN RELATION TO CONTROL WITHOUT COMPOST (= 100 %) RESULTS OF YEAR 2000 (KLUGE & BOLDUAN, 2003)

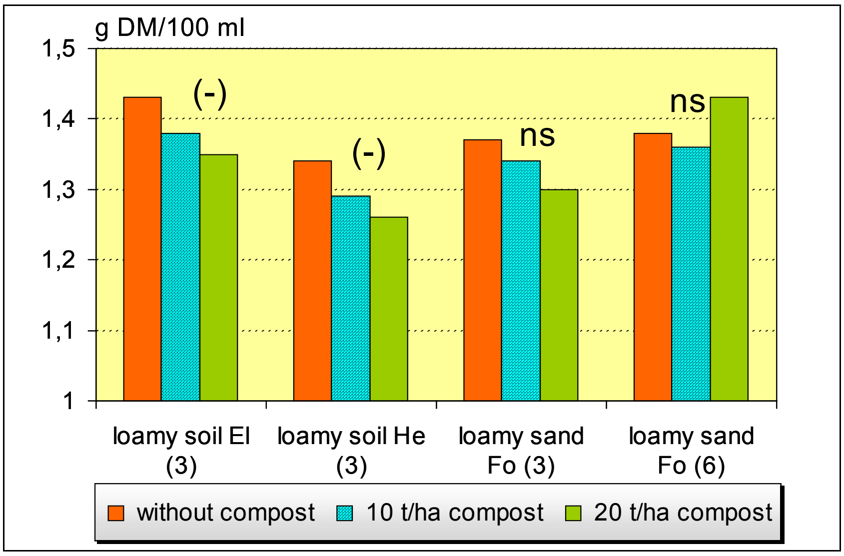


FIGURE 3-23: EFFECT OF COMPOST ON BULK DENSITY – RESULTS ABS. IN G SOIL (D.M.)/100 ML SOIL – LOCATIONS EL, HE AND FO, YEARS (3) AND (6), N.S. – NOT SIGNIFICANT, (-) – TENDENCY TO DECREASE (KLUGE & BOLDUAN, 2003)

Kluge & Bolduan (2003) confirmed that the physical soil properties are changing only over longer periods of constant cultivation. Only trends could be determined after 6 years of compost application of 10 Mg TM ha^{-1}in field tests.

First of all loamy locations reacted on a regular compost application with distinctly improved structures *(aggregate stability*) (Figure 3-22)

Parallel to this, soil density was reduced predominantly on more cohesive soils (Figure 3-23). Ebertseder (2003) could also prove in long-term tests (22 years) with relatively high compost supplies (52 resp. 104 Mg d.m. ha^{-1} every 3 years) the correlation between increasing C_{org} contents and increasing aggregate stability.

A positive effect on water household shows Figure 3-24. The water capacity was improved on three locations, here also on a light sandy soil.

This assures the water supply of plants even under unfavorable weather condi-tions (drought) for a longer time. On the other hand the infiltration of heavy soils improves. The uptake of heavy rainfalls is improved, soils can dry faster, the increased retaining power is a contribution to the reduction of run-off and flooding.

Finally both long-term tests over 22 years (Ebertseder, 2003) showed a distinct increase of the pore volume above all with pores of > 50 µm.

3.6.3 Conclusions from the symposium

The papers presented at the symposium (Amlinger et al, 2003c) confirmed the throughout positive effects of compost on soil structure and other soil physical properties (e.g. pore volume, soil density, water capacity, hydraulic conductivity and infiltration rate etc.) Concerning the physical soil properties aggregate stability seems to be the most important parameter of all. Contrary to many other parameters it can be easily measured.

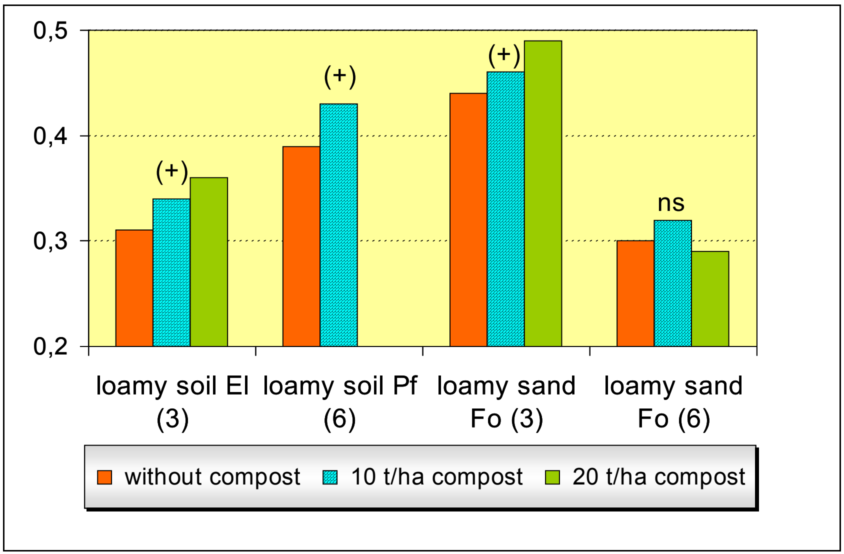


FIGURE 3-24: EFFECT OF COMPOST ON WATER CAPACITY – RESULTS ABS. IN G WATER/G SOIL (D.M.), LEGEND SEE FIGURE 3-23 (KLUGE & BOLDUAN, 2003)

For aggregate stability a change could only be stipulated with macro aggregates and micro aggregates > 20 µm. This is due to a slow transformation rate of such organic components, which are responsible for the stability of the smaller particles and which cannot be directly influenced over the cultivating measures. It proved that compost application most effectively improved the soil structure of sandy or silt soils.

The pore portion of >50 µm, predominantly in loamy soils, was increased in both long-term and short-term tests. Erosion tests proved: together with the decrease of bulk density and the increase of SOM compost causes a significant reduction of soil erosion and surface run-off.

The dynamic character of infiltration and erosion properties leads to the assumption that the latter do change over a longer period than the infiltration rate.

It was suggested that through a use of mineral components (stone dust, coal slate etc.) the potential for aggregate formation of compost can be enforced. This production of soils respectively a focussed management of soil functions is only possible with the help of compost. In this way mineral soil amendments can be improved through the incorporation into the soil formation process "composting" and the market value of compost possibly increased.

A lack of know-how about the correlation between the different organic fractions (*„pools"*) of the soil and the physical soil properties does certainly exist. Here is some research work still to be done in order to use composts of different qualities more purposefully for soil improving measures under the different soil conditions.

Connected with the structural effects of compost utilisation it was stipulated that it is not sufficient to consider <u>one</u> parameter as indicator, but several soil parameters together would allow an interpretation of soil improving effects.

The test result can be summarised in the following statements

- Reduction of soil density in most cases
- Increase of aggregate stability
- Increase of pore volume and the saturated hydraulic conductivity
- Reduction of soil erosion by increased stability of soil aggregates and the improved infiltration capacity
- With the improved soil structure (aggregate stability, coarse particle fraction) usually also increase of water infiltration of soils
- No unique trend of an increase of effective field capacity
- Results depend on soil, compost maturity and application rates
- Increase of macro pores, above all with higher compost rates
- Increase of soil temperature through darker soil colour

- Reduction of temperature fluctuation at very high compost rates
- Slower warming in spring through soil mulching and cooling effect at high temperatures in summer

3.6.4 The effect of compost on soil physical parameters – tabular survey

TABLE 3-24: THE EFFECT OF COMPOST ON SOIL STRUCTURE RESP. AGGREGATE STABILITY – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Effects on Aggregate Stability and Soil Structure				
Aggelides & Londra, 2000[SP300]	4 treatments on two soils (loam/clay) grass cover	0, 39, 78, 156 Mg MWSC ha^{-1}, (1994) single application,	Bulk density decreased sign. on both soils, by up to 20% (loam) resp. 17% (clay) at highest application rate Increased aggreagate stability	No information whether significance also applies to lowest application rate
Asche et al,. 1994[SP301]	7 loess-lessivé; single compost application	30 Mg RotM- and Comp each, with and without min. fertilisation, control	Bulk density decreased, not sign.	
Asche & Steffens, 1995[SP302]	7 loess-lessivé; single compost application	30 Mg RotM- and Comp each, with and without min. fertilisation, control	aggreagate stability (in percolation-test) raised by 56% in mature Comp and by 66% in immature Comp, differences not sign.	
Bazoffi et al., 1998[SP303]	argillaceous-loamy soil; effects of Comp and tyres on erosion and soil properties	Single application of 64 Mg d.m. ha^{-1}	Comp increased aggreagate stability sign. Bulk density increased.	Increase of BD caused by high content of inert material (glas)
Buchgraber, 2000[SP304]	Field trial, 5 years, 6 sites (1 grassland)	BWC, MC, gr.BWC	Soil aggreagate stability: pasture: 90 %; 3 farmland sites: 35 – 40 %, 20 – 30%, 10 – 15 %. NPK-fertilisation reduced stab. by 1-5%, gr BWC kept it at almost same level stability-increase in 5 years, detectable as trend.	aggregate stability ↑
Buchmann, 1972[SP305])	vineyard, stony-sandy loam from slate	control, 200 Mg ha^{-1} resp. 400/200 Mg ha^{-1} each MWC 1959 and 1965	With high application rate 1959 statistically confirmed increase of aggregate stability and lower bulk density	
Cole et al., 1995[SP306]	Silty soil contaminated with pestizides	Contaminated and non contaminated soil blend resp. GWC (dil. rates: contaminated soild.: 0; 1,5; 6; 12,5; 25, 50; 100 %)	Comp application reduced the bulk density.	Bulk density ↓
Ebertseder & Gutser, 2003a[SP307]	lessivé, loamy trial I: 3 years trial II: 22 years	Control without Comp trial I: 84 Mg d.m. BWC in 2 applications	Porevolume and –distribution: Comp application increased porenvolume, mainly because of an increase of the wide macropores > 50µm, slight increase of	↑ soil respiration, ↑ waterinfiltration,

Authors	Experimental Design	Fertilisation	Results	Remarks
	trial II: 22 years	trial II: 52 Mg resp. 104 Mg d.m. Comp every 3 years	narrow macropores between 10 and 50µm, with meso-pores and fine-pores no sign. difference aggreagate stability increased through Comp application on both trialplots	↓ erosion risk
Fliessbach et al., 2000[SP308]	longterm field trial since 1978; compare bio-dynamic (D), organisc (O) and conventional (K) cultivation (DOK-trial) CR: Pot, W-W, BR, W-W, Bar, 2x ley Luvisol on loess	Addition of org. matter during 7 years (2. CR-Periode): (D1): 1010 Kg ha^{-1}; (D2): 2.020 Kg ha^{-1} in form of MC_C (O1) & (O2): RotM; (K1) & (K2): StabM ca 1.000 resp. 2.000 Kg ha^{-1} each	High aggreagate stability in fertilized, low in unfertilized variations.	aggregate stability ↑
Fortun & Fortun, 1996[SP309]	Laboratory, sandy loam, argillaceous loam, clay	BWC, SSC, CM, 0%, 0,5 % and 1 %	Sandy loam: clear increase in aggreagate stability especially on aggregates with pre-treatment of water resp. beneze (2-6%), particularly with BWC, with benezene treatment also clearly on MC and SSC. Clay: increase of 2-5 % with different variations. Argillaceous loam: increase only for MC at low application rates and BWC at high rates (2-7 %).	aggregate stability ↑
Hein, 2000[SP310]	Sandy silt, compostproject Gumpenstein CR: Sil-M, SB, leyseed incorporation; ley during main season – Pot - S-R.	variations: Comp; RotM; Slu; NPK; PK. As assesment basis for fertilisation 2 LU ha^{-1}, fertilisation cropspecific application in spring.	All in all clear differences between different crops and within fertilisation variations high aggreagate (65 – 75%), with all ley-variations higher than 70 %. Mineral complete fertilisation has lowest aggreagate stability, but differences only 2 – 3 %.	aggregate stability ↑
Illera et al., 1999[SP311]	Field trial, 1 year, random. block, 3 replications., degraded, semiarid soil	Anaerobically treated Slu and BWC (with increased Cd, Pb and Zn-values) 0 and 80 Mg ha^{-1} d.m.,	12 months after application slight increase of SOM, compared to control, 26% with BWC (sign.) and 12% with SSC. BWC-variations darker soil colour. Slight decrease in particle- and bulk-density, slight increase in watercontent. Total Cd and Zn increased above 50%, Cu above 150% in comparison to control in $0^{-1}5$ cm.	
Lamp, 1996[SP312]	Brown soil from loessloam, several trials with MWC and BWC	Application amounts from 12 to 84 Mg d.m. ha^{-1} year	Percolation stability increased sign. on all trials; exception: MWC at applicationrates of 51 Mg d.m. ha^{-1} every three years; Bulk density decreased sign. with applications above 20 Mg d.m./year.	Percolation stability ↑ Bulk density ↓
Martins & Kowald, 1988[SP313]	lessivé, uL; CR: SW, O, W-W, SW;	6 variations. control, 40, 80, 120 Mg MWC without, 40, 120 Mg with min. fertilisation	Aggreagate stability increased sign. with all Comp variations, no stat. differences between variations, at 40 Mg application ~ approx. 30% increased stability	aggregate stability ↑

Authors	Experimental Design	Fertilisation	Results	Remarks
1988[SP313]	Compostapplication biannually	120 Mg with min. fertilisation	approx. 30% increased stability. Buld density decreased sign. with increased Comp application.	
Mbagwu & Piccolo, 1990[SP314]	5 soils from sL to T, aggregates were examined	40 Mg d.m. ha^{-1} Slu_P- resp. 200 T ha^{-1} Slu_C, resp. 8 Mg d.m. ha^{-1} Slu	Aggregate stability slightly increased: Bulk density decreased. No correlation betw. Corg content and aggreagate stability, but sign. correlation between aggreagate stability and humus resp. humic acid content.	no information regarding significance
Petersen & Stöppler-Zimmer, 1996[SP315]	lU and lS; FF. Ca, Pot, cereals, BR	5 variations: control, 30 resp. 100 Mg RotM- and MC each	Mature Comp stronger effect on aggreagate stability (as fraction of aggregates from 1- 2 mm) than immature Comp. Immature (fresh) Comp showed no effect at 30 Mg, immature (fresh) Comp at 100 Mg application rate shows same effect regarding aggreagate stability as mature Comp at 30 Mg application. Poren volume increase sign. through immature (fresh) Comp (100t) and mature Comp application, but only on sandy soils.	no statisctical significance regarding aggregate stability
Reinhofer et al., 1997[SP316]	3 years, loose sediment brown soil and pseudogley on dustloam, Corn-M – S-Bar -(Ra) - Corn-M	NPK and BWC in various combinations	No significant results	
Steinlechner et al., 1996[SP317]	Sandy loam, inhomogenous, org.	MC(172 Kg N ha^{-1}) and RM (93 Kg N ha^{-1}) 1995	No influence on soil temperature and aggreagate stability.	
Stewart et al., 1998c[SP318]	Field trial, sandigy loam, CR: M, Ca, Pot, Ca	0, 20, 40, 80 Mg ha^{-1} mushroom-substrate-waste before each seeding	Bulk density decreased significantly only in the variation with the highest application rate Aggregate stability increased significantly after 4 applications with all variations compared to 0-application (at 13 – 16 %) Decrease in daily temperature fluctuation.	bulk density↓, aggregate stability ↑, temperature fluctuations ↓
Timmermann et al., 2003[SP319]	Longterm compost trial (8 resp. 5 years): duofactorial split-plot facility with 12 variations at 4 replications. random. → 48 plots per experiment 6 Standorte : lS, uL, uL, utL, uL, sL CR: M – W-W – W-Bar	Comp application: 0; 5; 10; 20 Mg ha^{-1} N-supplementation level N0: no additional N-application level N1: 50 % of the optimal N- application level N2: 100 % of the optimal N-	Aggreagate stability: relatively high fluctuation rate of MV, especially with the controls, generally the Comp application has a positive stabilizing effect on aggreagate stability of the soilaggregates. Bulk density: judged on the whole trial period, in the mean of all dates a decrease of bulk density with Comp applications was observed for all sites, with relativley high fluctuations.	aggregate stability, bulk density

Authors	Experimental Design	Fertilisation	Results	Remarks
		application on basis of the Nmin-content of the soil as well as further aspects, like preliminary crop etc. (comp. nitrateinformationsservice - NIS).		

TABLE 3-25: THE EFFECT OF COMPOST ON HYDRAULIC CONDUCTIVITY – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Effects on Hydraulic Conductivity				
Aggelides & Londra, 2000[SP320]	4 variations on two soils (loam/clay) grasscover	0, 39, 78, 156 Mg MWSC ha^{-1}, (1994) single application,	Pore volume and saturated hydraulic conductivity increase sign., conductivity increases more with clay and pore volume with silt. Increase of macropores.	Pore volume ↑ saturated hydraulic conductivity ↑ No statement for lowest application rate
Asche et al,. 1994[SP321]	7 loess-lessivé; single compost application	30 Mg RotM and MC, with and without min. fertilisation, control	Pore volume and fraction of macropores did not increase sign. with immature (fresh) Comp.. Sign. increase of the mediumpore fraction. Fine pore fraction decreased.	
Lamp, 1996[SP322]	Brown soil from loessloam, several trials w. MWSC and BWC	Application amounts from 12 to 84 Mg d.m. ha^{-1} year	Conductivity increased with all Comp applications, because of high deviation no statist. vailidity	
Mamo et al., 2000[SP323]	Field trial, 3 years, loamy sand, irrigated M, soil moisture, water retention capacity	0 and 90 Mg ha^{-1} 1993 and 1995, single application of 270 Mg ha^{-1} 1993.	Comp application did not increase laboratory tested water availability. Single, high comp application increased waterstress of the plants during the year of application, but did not cause yield reduction. During 2nd year increase in plantavailable water and grain yield, compared to annual applications and control.	
Martins & Kowald, 1988[SP324]	lessivé, uL; CR: SW, O, W-W, SW; compost application every two years	6 variations. control, 40, 80, 120 Mg MWC without, 40, 120 Mg with min. fertilisation	Pore volume increased, sign. starting at 80 Mg ha^{-1}, further increase of application rates did not raise total pore volume; The fraction of macropores was increased, but narrow macropores and mediumpores showed no sign. increase.	
Petersen & Stöppler-Zimmer, 1995[SP325]	lU and lS; CR: Ca, Pot, cereals, BR	5 variations: control, je 30 resp. 100 Mg RotM and MC	Pore volume increased sign. through application of immature (fresh) Comp (100 Mg) and both mature Comp, but only on sandy soils.	No statement on type of pores found.

TABLE 3-26: THE EFFECT OF COMPOST ON INFILTRATION AND EROSION – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Effects on Infiltration and Erosion				
Aggelides & Londra, 2000[SP326]	4 variations on 2 soils (loam/clay) grasscover	0, 39, 78, 156 Mg MWSC ha^{-1}, (1994) single application,	Pore volume and saturated conductivity increase sign., conductivity increases more with clay and pore volume with silt.	No information, on sign. Results at lowest application rate
Asche et al,. 1994[SP327]	7 loess-lessivé; single compost application	30 Mg RotM and MC, with and without min. fertilisation, control	Pore volume and fraction of macropores did not increase sign. With immature (fresh) Comp sign. increase of the mediumpore fraction. Fine pore fraction decreased.	
Bazoffi et al., 1998[SP328]	argillaceous-loamy soil; effects of compost and tyres on erosion and soil properties	Single application of 64 Mg d.m. ha^{-1}	Run-off and erosion were reduced during the 3-year observation period, sign. not always given.	
Bosse, 1968[SP329]	vineyard, 58 % slope, 9 years, slopeloam from shale and sleitsandstone, measurement of waterdischarge and soil erosion	MWC, 1959: 200 resp. 400 Mg ha^{-1}; 1965: 200 resp. 200 Mg ha^{-1}	Erosion reduced through MWC, to 58,5% (400 Mg ha^{-1}) resp. 33,3 % (600 Mg ha^{-1}). Total tun-off (soil and water) reduced to 77,1 and 55,1 %. Eroded soil of control contained 29 % clay, Comp plots 24 % and 16 %.	erosion ↓
Klaghofer et al., 1990[SP330]	Field trial, 4 years, vineyard, 5 – 8 ° slope, shallow, calcareous, high sandfraction, erosion endangered, rainsimulator experiments	BWC 75 Mg ha^{-1}, 150 Mg ha^{-1}	In Sept. 1984, during a natural strom-water incident (strom-water incident, 28,3 mm) on control 11 Mg ha^{-1}, on 75 Mg MC ha^{-1} 7 Mg ha^{-1} and on 150 Mg MC ha^{-1} 8 Mg ha^{-1} were eroded. The application of MC reduced erosion only by 40%. During the irrigation-sprinkler-trials 1984 the highest erosion was found on 150 BWC-plot, the lowest on 75 BWC-plot, 1985 the least erosion was found on control, the highest on 150 MC-plot.	erosion ↓
Lamp, 1996[SP331]	brown soil from loessloam, several trials w. MWSC and BWC	Application amounts from 12 to 84 Mg d.m. ha^{-1} year	Pore volume and fraction of macropores increased sign. with application amounts above 20T/d.m. ha^{-1}/year	
Martins & Kowald, 1988[SP332]	lessivé, uL; CR: SW, O, W-W, SW; Compost application every two years	6 variations. control, 40, 80, 120 Mg MWC without, 40, 120 Mg with min. fertilisation	Pore volume increased, sign. starting at 80 Mg ha^{-1}, further increase of application rates did not raise total pore volume; The fration of macropores was increased, but narrow macropores and mediumpores showed no sign. increase.	
Ozols et al., 1997[SP333]	lessivé-pseudogley (Ut3), rainsimulator 62,7 mm/h four	100 m³ f.m. ha^{-1} GWC, 10 Mg d.m. ha^{-1} BWC;	Run-off: 7 – 8 l/m^2*min. The mulch-layer counteracted erosion considerably: GWC 93%, Comp 64% compared to control. A	erosion ↓

Authors	Experimental Design	Fertilisation	Results	Remarks
1997[SP333]	rainsimulator 62,7 mm/h four weeks after application of Comp and chaff. Continual sampling of surface runoff.	Mg d.m. ha^{-1} BWC; soilcoverage on mulch plots: 75 – 90%, control: 15 – 30%.	considerably: GWC 93%, Comp 64% compared to control. A surface application of Comp is not recommended on erosion-endangered soils, das Eutrophication potential is considerably higher for BWC than for GWC.	
Petersen & Stöppler-Zimmer (1995[SP334])	lU and lS; CR: Ca, Pot, cereals, BR	5 variations: control, 30 resp. 100 Mg RotM and MC	Pore volume increased sign. through application of immature (fresh) Comp (100 Mg) and both mature Comp, but only on sandy soils.	No statement on type of pores found.
Schonbeck & Evanylo, 1998[SP335]	Field trial, 5 soils: lS, sL, L, uL, sL	No mulch, GWC, barkmulch (5 resp.10 cm layer each)	Comp had a cooling effect on the soil, the soilmoisture below the mulch was the highest, resulting from possible infiltration and reduced evapoaration.	temperature ↓, soilmoisture ↑
Stewart et al., 1998c[SP336]	Sandy loam, CR: M, Ca, Pot, Ca	0, 20, 40, 80 Mg mushroom-substrate-waste before each seeding	Infiltration rate increased after 4 applications on all levels, but not sign., (by 130 – 207 mm/h) Reduction of lumping and crust formation (16 – 31 and 18 – 94 %) sign. above application rates of 40 Mg	crust formation ↓, infiltrationrate ↑,
Strauss, 2003[SP337]	pseudogleyified loose sediment - brown soil; rainsimulator: 1 mm/min for 1 h	control, MC, CMC-Comp at application rates from 12 to 24 Mg	Soil loss on the compost variations about 1/3 compared to control, earlier and more runoff on control	erosion ↓

TABLE 3-27: THE EFFECT OF COMPOST ON FIELD CAPACITY – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Effects on Field Capacity				
Aggelides & Londra, 2000[SP338]	4 variations on 2 soils (loam/clay) grasscover	0, 39, 78, 156 Mg MWSC ha^{-1}, (1994) single application,	Field capacity increases significantly only on loam.	No information whether significance is also valid for lowest application
Asche et al,. 1994[SP339]	7 loess-lessivé; single compost application	30 Mg RotM and MC, with and without min. fertilisation, control	Pore volume and fraction of macropores did not increase sign. With immature (fresh) Comp sign. increase of the mediumpore fraction. Fine pore fraction decreased.	
Bohne et al., 1996[SP340]	deep, decalcified lessivé from loess over terrace gravel	BWC 785 dt ha^{-1}, 3000 dt ha^{-1}, horse manure 535 dt ha^{-1}	Total pore volume, especially the fraction of macropores increased. At the end of the 2nd year only the Comp plots with high Comp application had a tendencially higher pore volume, which was then based on the increase of meso pores in comparison to control.	Porenvolumen ↑
Eyras et al., 1998[SP341]	Vesselexperiment, Tom	Seaweed Comp at various application rates on different soils	The water retaining capacity increased in the lowest case by 5% (at 10% Comp) in the highest case by 32% (100% Comp) from 20% (in washed sand) to 52,6% absolute (on the 100% variation). On all Comp variations the yield loss caused by water stress 0% in comparison to 83% on control.	water retaining capacity ↑
Gagnon et al., 1998b[SP342]	Sandy loam and clay soil	4 Comp with 4 N-levels (0, 45, 90 u. 180 Kg N ha^{-1}), twice	The higest comp application on all comp plots increased soil mositure sign. on all sandy loam soils, no effect on clay soil.	application rates between 3 and 30 Mg d.m. in 2 years
Lamp, 1996[SP343]	Brown soil from loessloam, several trials w. MWSC and BWC	Application amounts from 12 to 84 Mg d.m. ha^{-1} year	No change on meso pores.	
Martins & Kowald, 1988[SP344]	lessivé, uL; CR: SW, O, W-W, SW; Compost application every two years.	6 variations. Control, 40, 80, 120 Mg MWC without, 40, 120 Mg with min. fertilisation	Pore volume increased, sign. starting at 80 Mg ha^{-1}, further increase of application rates did not raise total pore volume; The fration of macropores was increased, but narrow macropores and mediumpores showed no sign. increase.	

Petersen & Stöppler-Zimmer (1995[SP345])	lU and lS; CR: Ca, Pot, cereals, BR		Pore volume increased sign. through application of immature (fresh) Comp (100 Mg) and both mature Comp, but only on sandy soils.	Keine Aussagen welche Poren verstärkt vorkommen
Pickering et al., 1997[SP346]	Mulch on sandy claysoil	control, PE(Polyethylen-mulch), 2 Comp (Slu+bark; MWC)	Mulch increased soil moisture sign. during summer months, GWC better than bark mulch.	No information on data
Pinamonti, 1998[SP347]	Field trial, 6 years, vineyard, calcareous soil, 15 % slope, semisandy, stony	5 variations: control, 30 resp. 100 Mg RotM and MC each	Both Comp improved porosity as well as water retaining capacity.	porosity ↑, water retaining capacity ↑
Pinamonti & Zorzi, 1996[SP348]	Field trial since 1986, 16 vineyards, 14 fruit orchards, and damaged land (skislopes, devastated roads, abandoned quarries, eroded regions)	MWC and SSC (Slu: poplar barc 1:2 vol), various application types and rates	Sign. increase of available soilmoisture and porosity.	
Schonbeck & Evanylo, 1998[SP349]	Field trial, 5 soils: lS, sL, L, uL, sL	No mulch, GWC, bark mulch (5 resp. 10 cm layer)	Comp had a cooling effect on the soil, the soilmoisture below the mulch was the highest, resulting from possible infiltration and reduced evapoaration.	Temperatur ↓, Bodenfeuchte ↑
Serra-Wittling et al., 1996[SP350]	Argillaceous silt	Comp, plastic, hay, paper-mulch	Fieldcapacity increased sign.	Extremly high addition, goal was effect on substrates
Shiralipour et al., 1996[SP351]	Greenhouse, broccoli, lettuce, yield, water retaining capacity, loamy sand, loam and argillaceous loam	BWC; 0, 15, 30 and 60 Mg d.m./acre	Increase of water retaining capacity at 60 Mg d.m./acre by 15 % on sandy loam, 14 % on Lehm, 5 % on argillaceous loam.	
Smith, 1996[SP352]	Natioanwide research programm in Florida	Various MWC resp. BWC with and without Slu	Soil-water-retention increased	
Steffen et al., 1994[SP353]	3-year Field trial; CR: Tom – Sweet-Corn – bean – broccoli/Ca; 3 replications. silty loam	Single application 1990: 64 Mg d.m. ha^{-1} SMC; 57 Mg d.m. ha^{-1} RotM (= je 2.700 Kg N ha^{-1} [!]), NPK. incorporation 20 cm, NPK with black PE-foil; SMC and RotM with 10 cm mulched	1990: no sign. increase of the average available soilwater content, 1991: available soilwater content 2,7 times greater than without Comp application	

		St., succeeding crop fertilized only in NPK-plots according to drop demand.		
Stewart et al., 1998c[SP354]	Field trial, fine, sandy loam, 2 years, vegetables	0, 20, 40, 80 Mg ha^{-1} mushroom-substrate-waste before each seeding	Bulk density decreased, increase of aggregate stability (by 13 – 16 %), reduction of lumping and crust formation (16 – 31 and 18 – 94 %), increase of infiltration rate (by 130 – 207 mm/h), increase of soil-water content (by 0 – 7 % w/w), decrease in daily temperature fluctuations, partially above 80 Mg ha^{-1}.	bulk density ↓, aggregate stability ↑, crust formation ↓, infiltrationrate ↑, water content ↑, temp.
Stewart et al., 1998b[SP355]	Incubation experiment, Lysimeter on field, sandy loam, CR: M, Ca, Pot, Ca	Soil with Comp addition of 10, 30 and 100 % f.m.	No effect on field capacity and soil moisture.	
Tenholtern, 1997[SP356]	Large parcel facility, 3 years, no rep., Kultosol, single application	SMC 0, 20, 40, 80 Mg ha^{-1} moist with and without NPK; 0, 40, 120 and 360 Mg ha^{-1} f.m.	Sign. increase of meso pores (10-0,2 µm) with application rates of 360 Mg ha^{-1}	
Timmermann et al., 2003[SP357]	Long-term compost experiment (8 resp. 5 years): duofactorial split-plot facility with 12 variations at 4 replications. random. → 48 plots per experiment 6 sites : lS, uL, uL, utL, uL, sL CR: M – W-W – W-Bar	Comp application: 0; 5; 10; 20 Mg ha^{-1} N-supplementation level N0: no additional N-application level N1: 50 % of the optimal N- application level N2: 100 % of the optimal N-application on basis of the Nmin-content of the soil as well as further aspects, like preliminary crop etc. (comp. nitrateinformationsservice - NIS).	No uniform trend toward an increase of usable field capacity. Site specific changes in the pore spectrum, caused by Comp.	

TABLE 3-28: THE EFFECT OF COMPOST ON SOIL AIR AND POROSITY – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Effects on Gasdiffusion				
Aggelides & Londra, 2000[SP358]	4 variations on 2 soils (loam/clay) grasscover	0, 39, 78, 156 Mg MKK ha^{-1}, (1994) single application,	Fraction of wide macropores increased sign. , higher increase with silt.	no information whether sign. also applies to lowest application
Asche et al,. 1994[SP359]	7 loess-lessivé; single compost application	30 Mg RotM and MC, with and without min. fertilisation, control	No sign. increase in porevolume and fraction of macropores not Porenvolumen.	
Buchmann, 1972[SP360])	Vineyard, stony-sany soil from slate	control, 200 Mg ha^{-1} resp. 400/200 Mg ha^{-1} MWC 1959 and 1965	With high application rate 1959 statistically confirmed increase of macropores.	
Lamp, 1996[SP361]	Brown soil from loess, several trials w. WSC and BWC	Application amounts from 12 to 84 Mg d.m. ha^{-1} year	Porevolume and fraction of macropores increased sign. with application rates above 20 Mg d.m. ha^{-1}/year	
Martins & Kowald, 1988[SP362]	lessivé, uL; CR: SW, O, W-W, SW; Compost application every two years	6 variations. control, 40, 80, 120 Mg MWC without, 40, 120 Mg with min. fertilisation	Pore volume increased, sign. starting at 80 Mg ha^{-1}, further increase of application rates did not raise total pore volume; The fraction of macropores was increased, but narrow macropores and mediumpores showed no sign. increase.	
Tenholtern, 1997[SP363]	Large parcel facility, 3 years, no rep., Kultosol, single application	SMC 0, 20, 40, 8 Mg ha^{-1} moist with and without NPK; 0, 40, 120 and 360 Mg ha^{-1} f.m.	Sign. increase of wide macropores (>50 µm) at an application rate of 40 Mg ha^{-1}	
Timmermann et al., 2003[SP364]	Long-term compost experiment (8 resp. 5 years): duofactorial split-plot facility with 12 variations at 4 replications. random. → 48 plots per experiment 6 sites : lS, uL, uL, utL, uL, sL CR: M – W-W – W-Bar	Comp application: 0; 5; 10; 20 Mg ha^{-1} N-supplementation level N0: no additional N-application level N1: 50 % of the optimal N- application level N2: 100 % of the optimal N- application on basis of the Nmin-content of the soil as well as further aspects, like preliminary crop etc. (comp. nitrateinformationsservice - NIS).	Different site specific effects of Comp on the air volume (increase resp. tendency towards decrease)	

TABLE 3-29: THE EFFECT OF COMPOST ON SOIL TEMPERATURE – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Effects on Soil Temperature				
Baldock & Nelson, 1999[SP365])			Mulch may cause a slower warming of the soil in spring.	
Hartmann (2003[SP366]) cit according to Mayer FAL	Podsol and lessivé	Compost application 60 m^3 ha^{-1}	Darker coloration – during the day more energy-intake; during the night less energy emission → more balanced daily radiation-balance amplitude. Surfacetemperature: no difference on light Podsol, lessivé tendencially higher with Comp application Mean soil-temp. in 3 cm and 5 cm depth: no difference; Minimal-temp. on Comp fertilized plots slightly increased. → Temperature amplitudes more balanced. Up to two days after Comp application the mulch causes a decrease in the daily maxima Bis zwei Tage nach Kompostapplikation bewirkt Mulchschicht Verringerung der Tagesmaxima by 1 – 2 °C in 3 and 5 cm depth, reduced temperature radiation during the night.	
Pickering et al., 1997[SP367]	Mulch on sany clay soil	Without mulch, GWC, bark mulch (5 bzw. 10 cm layer each)	Mulch decreases soil temperature sign. during summer months, sign. with GWC only in May.	No information on data
Pinamonti, 1998[SP368]	uS, vineyard, Comp as mulch	2 Comp, 37 resp. 42 Mg d.m. ha^{-1}	Mulch decreases soil temperature during summer months by ca. 1°C and increased it in spring and early summer by ca. 1°C in comparison to non-mulches plot	
Poletschny, 1995[SP369]			Comp fertilisation caused humus enrichment → darker coloration of the soil → better warming especially in spring (up to 1° C)	No information from experiments
Schonbeck & Evanylo, 1998[SP370]	Field trial, 5 soils: lS, sL, L, uL, sL	Comp, plastic, hay paper-mulch	Comp had a cooling effect on soil	temperature ↓, soilmoisture ↑
Stewart et al., 1998c[SP371]	Sandy loam, CR: M, Ca, Pot, Ca	0, 20, 40, 80 Mg ha^{-1} SMC before seeding	With the highest application rate, the temperature fluctuation of the soil decreased	

3.7 Heavy metals – accumulation, mobility, uptake by plants

3.7.1 General aspects of heavy metal sorption and solubility

Soil organic matter has probably the greatest capacity and strength of bonding with most trace metals of any soil component (the possible exceptions are some non-crystalline minerals with very high surface areas). As a consequence there are often statistically significant correlations between solubility of trace metals such as Cu, Hg and Cd, and Soil Organic Matter Content.

Frequently organic soils or organic soil horizons with high values of trace metals, for example Holmgren et al. (1993) showed for a range of soils from the USA correlation between levels of Cd, Cu, Zn, Pb and Ni and soil organic matter content. The strongest relations were for total Cd and SOM (g Kg^{-1} soil)::

$Cd_T = 0{,}10 + 0{,}0094\ SOM \quad r = 0{,}51 \quad (P<0{,}01)$

The relationship possibly relates to bio-accumulation and retention against long term leaching.

The functional groups in soil organic matter, principally carboxylic and phenolic, but also amine, carbonyl and sulphhydryl groups are the key to the bonding of metals. The bonding strength of these functional groups varies considerably. Large metal additions force bonding onto the predominant groups (carboxyl). In this case Cu is often found to have weak bonding strength.

3.7.2 Metal absorption rates in SOM

The sorption reactions with SOM generally follow the following patterns:

Cr(III) > Pb(II) > Cu(II) > Ag (I) > Cd (II) = Co(II) = Li(II).

Generally the metals that bond most strongly to SOM tend also to be the most rapidly adsorbed. Most metals Pb^{3+}, Cd^{2+}, Cu^{2+} and Fe^{3+}) when complexed with soil organic matter have low lability. In contrast dissolved humic and fulvic acid-metal complexes of metals such as Cu^{2+}, Ni^{2+} and Co^{2+} appear to be largely labile. Lability is particularly sensitive to pH and metal/organic ratio, decreasing as pH is raised and as the metal/organic ratio is decreased. (Petruzzelli & Pezzarossa, 2003; Leita et al., 2003).

The phenomena described is that compost amendments result in a re-distribution of metals from exchangeable to less soluble fractions. This is preferably true for stable (well humified) organic materials (Schuman 1998 and 1999 for Cd, Pb and Zn).

The humic substances can interact with the metals forming complexes and chelates of varying stability. The complexes of the heavy metals with the organic matter of the soil can have different solubility and therefore a different environmental mobility. The thermal and water regimes of the soil influence the processes of oxide-reduction of the heavy metals and the more general decomposition processes of the organic matter of the compost. The depth of soil tillage is also important because it determines the nature of the contact and the reactions between the metals and the soil constituents (Pertuzzelli & Pezzarossa, 2003[SP372]).

3.7.3 Concepts of sustainable compost use

The recycling and use of secondary resources (i.e. nutrients, OM) may be accompanied by the import of potentially toxic elements (PTEs) into the agro-eco system. The beneficial effect of nutrient recovery from reuse of organic waste-products in agriculture should not counter environmental or specifically soil protection policies. However in most cases admissible heavy metal inputs to soil via fertilisation exceed the average export by harvested crops, erosion or leaching. So the result would be a positive balance (Gäth, 1998[SP373]).

Obviously the environmental evaluation of this imbalance is discussed controversially. On the one hand short to mid term practical field studies show no measurable change in soil concentrations. On the other hand some accumulation scenarios consider some 10 up to several 100 years until it can be expected that a critical soil threshold value may be reached (Gäth, 1998[SP374]; Sauerbeck, 1994[SP375] and 1995[SP376]).

Since heavy metals show little mobility and react in manifold ways with solid soil phase (Scheffer & Schachtschabel et al., 1998[SP377]) a positive balance lead to accumulation and increase of metal concentration in soil. This of course depends on cultivation depths, soil density and balance.

The key question for the derivation of environmentally sound and practicable quality requirements therefore is: can a certain heavy metal accumulation in soil be tolerated (in addition to atmospheric deposition) as long as scientifically derived threshold values for the multifunctional use of soil would not be exceeded?

Following the logic of such a soil threshold which already respects concerned pathways and subjects of protection in a precautionary way, the answer can only be yes. But, at the same time it is agreed that for any fertilisation system all management tools must be applied to minimise the input of potential toxic elements. The latter implies to achieve the best achievable quality by the way of exclusion of potential contaminated source materials, the reliance on source separation systems org organic waste materials an the application of a quality management and assurance system at all steps of production.

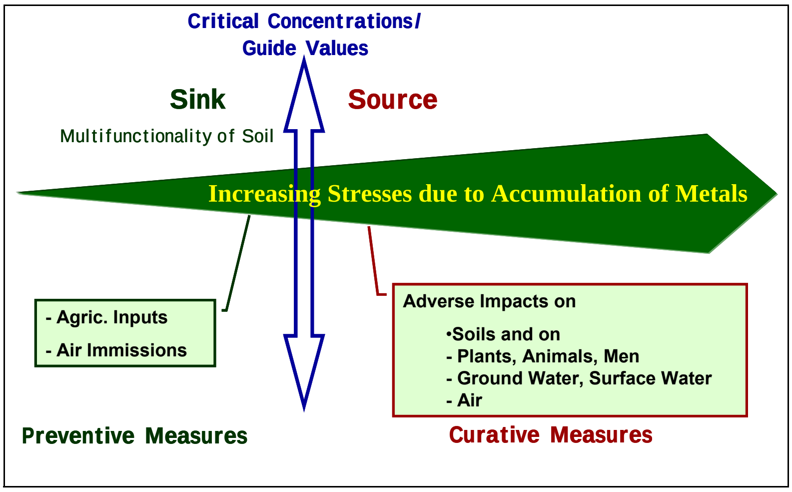


FIGURE 3-25: CRITICAL CONCENTRATION DECIDES WHETHER THE SOIL SERVES AS SINK OR SOURCE OF POTENTIAL POLLUTANTS (GUPTA, 1999[FA378])

Contaminants that accumulate might not have adverse effect until their active concentration exceeds a (critical) threshold value. Contaminants might also be substances that when render the soil, may constitute a contaminating source for other media, for example a substance that is deposited on soil and then transferred to water.

This leads to the necessity of soil reference, guide or threshold values which enable us to judge whether a potential charge with pollutants might cause a risk or not:

The *critical concentration* marks the threshold from where, when exceeded, the soil pass from a *sink* into a potential source of *'risk compounds'* to a receptor. This critical concentration must be based on experimental and field experience derived from eco-toxicological effects over defined pathways. With this static value still nothing is said, if the released contaminant would have a toxicological relevance for the final receptor media or entity concerned.

The final definition of a guide value for the multifunctional (predominantly agronomic) use of soil depends very much on the traditional perception of the *value of soil* as such and the qualitative and quantitative assessment of soil functions. This can then lead to a more or less precautionary approach (introducing a wider or smaller safety buffer).

This makes clear that – besides identifying a distinct ecological or agronomic benefit – in order to assess a long term fertilisation system with respect to a potential heavy metal accumulation precautionary, critical soil threshold values serve as the orientating starting point.

Thje concept that has been proposed by Amlinger et al. (2004) is here summarised.

3.7.3.1 Approaches on risk assessments

Starting point for a number of concepts which have been put forward for the use of secondary raw materials as fertilisers is an equitable estimation of the beneficial effects balanced against the potential risks caused by potentially present contaminants (Wilcke and Döhler, 1995[FA379]; Hackenberg and Wegener, 1999[FA380]; Bannick et al. 2001[FA381]; Kranert et al., 2001[FA382]; Bannick et al., 2002[FA383]; Severin et al., 2002[FA384] among others).

In a first approach we may distinguish 2 basic concepts:

1.) Risk based assessment such as the No Observable Adverse Effect Levels (NOAEL) concept

2.) Mass balance or No Net Degradation (precautionary approach)

Between those two polarities manifold hybrid systems such as PNEC (*predicted no effect concentration*) are discussed.

What is commonly agreed is that any concept should provide long term safe food and feeding stuff production and the protection of the water recourses.

The Part 503 NOAEL risk assessment identifies various potential routes for exposure following the use of sewage sludge in agricultural production. 14 different pathways were assessed. On the basis of available data the risk associated with each of the pathways has been calculated. The threshold for a particular contaminant is the value generated by the pathway resulting in the lowest concentration that represented an acceptable risk according to the US EPA analysis. For 5 of the 9 regulated contaminants the pathway of direct ingestion of sludge by children was the limiting path, generating the lowest acceptable level.

Many of the assumptions and the underlying approach have been commented and criticised (Harrison et al., 1997, Fürhacker et al., 1999) US EPA approach exceeds the maximum load (1,6 - 2,5 Mg $ha^{-1-1}a$ d.m.) of existing sludge regulations in European countries (e.g. CH, A, FR) 1.5 to 4 times. In effect the admissible yearly or cumulative load for Cd of US EPA Part 503 would lead to the following increase of Cd concentration in the soil (20 cm soil depth with 3,000 Mg ha^{-1}):

BULK SLUDGE: Cumulative load = 39 Kg Cd ha^{-1} ➔ ~ + 13 mg Kg^{-1} soil d.m.

BAG SLUDGE: Yearly load = 1.9 Kg Cd ha^{-1} ➔ ~ + 0.63 mg Cd Kg^{-1}soil d.m. $year^{-1}$

Drawing the baseline at typical background concentrations for Cd in European soils (0.20 – 0.70 mg Kg^{-1} d.m) it becomes evident that the NOAEL strategy uses soil as a sink for Cd until an actual adverse effect may be expected for any of the exposures adopted. Protective aspects in the sense of maintaining the soil quality on an existing level are of no relevance.

In contrast *No Net Accumulation* concepts concentrate on the preservation of soil quality as such. Thus all possible inputs into the soil (also seen together with water protective aspects) must be evaluated and limited, also on the background of all future exposures. The most purist interpretation demands: *no increase of the contaminant pool*. A first level of tolerance takes into account all exports by harvested crops and leaching and limits any input to a quantity that would not change soil concentration.

Respecting the compost qualities produced from source separated biowaste and garden waste this concept would limit compost rates to 2-3 tons d.m. per ha and year. As a result the intended benefits of humus reproduction etc. could not be achieved following good practice of compost fertilisation.

The concept proposed by Bannick et al. (2002[FA385]) derives permissible concentrations in (organic) fertilisers (sludge, compost, manures and slurries) from the precautionary values of the Soil Protection Ordinance in Germany. The principle adopted here was the *"limitation of pollutant loads to a concentration level corresponding to soil background concentration "*

TABLE 3-30. PROPOSED LIMIT VALUES FOR COMPOSTS FOLLOWING BANNICK ET AL. (2002) IN COMPARISON TO EXISTING QUALITIES IN EUROPE.

	Soil type	Cd	Cr	Cu	Hg	Ni	Pb	Zn
limits from Bannick et al. (2002)	clay	1.63	107.01	70.08	1.10	75.94	107.63	260.57
	Loam/silt	1.10	64.41	48.78	0.56	54.64	75.68	207.32
	sand	0.46	32.46	27.48	0.14	17.36	43.73	111.47
BWC low (1)		0.50	23.0	45.1	0.14	14.1	49.6	183
BWC high (2)		0.87	39.9	73.9	0.30	27.0	87.6	276

(1) average of **mean or median values** from European compost surveys (*biowaste composts;*)

(2) average of **90th percentile values** from European compost surveys (*biowaste composts*)

It has been estimated that in Germany on facility level only 10 %, 42 % and 62 % of 376 composting plants may guarantee in average the proposed limit values for sand, loam and clay soils respectively.

An evaluation of the Austrian data showed that only 38.9 % of 582 biowaste (=501) and green compost (=63) meet the requirements for biowaste compost use of the EU Regulation (EEC) No. 2092/91 on organic farming. Compost from cities fulfil this requirement only in 20 – 26 % whereas for rural areas this proportion amounts 44.5 %.

3.7.3.2 Derivation of quality requirements and application regimes – weighing benefits and precaution

Some of the principles or basic considerations of the aforementioned no net accumulation concepts can be endorsed as reasonable step within a comprehensive perception of fertilising systems. At least one is the definition of beneficial effects and the adoption of GAP in terms of soil improvement and plant nutrition.

In order to recognise the full range of benefits, specifically of organic soil amendments such as compost the potential adverse effects by contaminants inputs have to be assessed on a mid-term basis independently from the application regime which has been derived from GAP requirements.

The latter can differ significantly when considering the site and management specific demands. This can be e.g. (i) a continuous low rate for the maintenance of a given SOM status or (ii) a short-term humus amelioration on degraded sites with higher application rates for a period of e.g. 10 years.

The following general, step-wise approach, here explained with compost, would be a feasible procedure which can be applied for all types of fertilisers and contaminants. The variable parameters like (background concentrations in soils, leaching rates, applications rates of fertilisers etc.) can be adapted for any individual scenario and fertilisation system.

Step 1: Identify the benefits of the fertiliser/soil amendment to the agro system (relevant amounts of om or plant nutrients)

Agronomic benefit follows good agricultural practice (GAP) (Nutrient/OM supply) including eventual necessary limitations related to e.g. water conservation or N_2O emissions. This must also include enough flexibility considering the organic sorption/binding dynamic of nitrogen. This cannot be neglected in the comparison of e.g. compost, liquid manure or mineral N-fertiliser (Amlinger et al., 2003a; Amlinger et al. 2003b[DFA386], Timmermann et al. 2003).. Thus short-term and mid-term effects of added organic matter and plant nutrients in terms of plant nutrition, build-up of nutrient and SOM stocks and the likelihood of being leached to the groundwater have to be considered in order to define best practice of beneficial management. This gives an optimum range of quantities to be applied under the diverse agronomic/site/cultivation conditions (also for soil amelioration on degraded sites).

Step 2: Identify potential pollutants which may have any adverse effects to the agro-ecosystem, to the environment or the food chain

Identify the potential pollutants (inorganic and organic) and evaluate the potential risks under short/mid and long-term management scenarios identified for good agricultural practice in step I. For PTEs (*heavy metals*) this is apparently an easy exercise though we still have to distinguish between metals which play an essential role as trace elements (Cu, Zn and partly Cr) and others where up to now no beneficial effect was identified. But consider, in some cases a “too much” of copper and zinc could be identified. In the case of xenobiotic organic pollutants the answer to the question if a certain substance occurring in manure or compost pause a risk is much more complex. (Uncertainties of concentration-dose relation in the considered pathways as well as still unknown dynamics of decay, sorption and metabolism of the huge number of specified compounds exist).

Step 3: Define the limiting factor and evaluate an application regime considering the aspects of precaution

This follows GAP with balanced OM and nutrient supply (preventing a surplus over a certain time frame) by observing potential accumulation of PTEs against threshold values for multifunctional use of soils (e.g. Austria: ÖNORM L 1075; Germany: Federal Soil Protection Ordinance, BBodSchV, 1999). Subsequently the potential accumulation of pollutants in time (e.g. between 50 and 200 years) must be evaluated and decision must be taken whether the speed of the accumulation or the probable exceeding of precautionary soil thresholds are acceptable or not.

Step 4: Response to the outcome of step 3

This could be:

- reducing the input by means of technological improvement of the material (waste or product) or limiting the quantity to be applied (plant/soil use)

or

- accepting the management system (GAP) due to the fact that on a long-term scale multifunctional threshold values of soil are not exceeded.
- setting maximum concentrations for fertilisers taking into account tolerances of local, seasonal, sampling and analytical variances

When considering the adoption of scenarios in which we would accept a controlled and very slow input of PTEs to the soil, which does not constitute any risk in a given time horizon, this approach

1. does take full advantage of beneficial effects of organic matter and nutrients supply especially from compost to the soil eco system
2. constitutes a driver for an overall technological improvement of industrial processes over time, in order to have a steady improvement of quality of composts or digestates, its input from feedstock and overall immissions to the environment – this arguably would not happen in the case of a regulatory approach which would imply cutting off any possible application for much of the composted products (e.g. *'similar to similar concept'*)

A concept based purely on absolute figures of annual metal loads might be simple but from a scientific and ecological standpoint it must be objected.

In the following the assumptions made for the accumulation model of PTEs in the soil are summarised.

- **Soil guide respectively threshold values assuring multifunctional use of soils**
  - Precautionary values of the German Soil Protection Ordinance for "sand" und "clay"(BBodSchV, 1999 [FA387])
  - Proposal for a revision of soil limit values in the frame of an EC Sewage Sludge Directive by the Joint Research Centre (JRC) of the EU Commission, Institute for Environment and Sustainability, Soil and Waste (Langenkamp et al., 2001[FA388])

		Cd	Cr	Cu	Hg	Ni	Pb	Zn
Soil guide value "SAND"	mg Kg^{-1}d.m.	0.4	30	20	0.1	15	40	60
Soil guide value "CLAY"	mg Kg^{-1}d.m.	1.5	100	60	1.0	70	100	200
JRC proposal soil: pH 6-7	mg Kg^{-1}d.m.	1	75	50	0.5	50	70	150

- **Concentration of PTEs in composts**

  Median (Med) and 90th percentile of BWC of national investigations and statistically weighted figures used as representative concentration (data of 7 European countries)

- **Heavy matel exports**

  Mean export by harvested crops (cereals, maize, sugar beet, potatos) and leaching taken from Bannick et al. (2001[FA389])

- **Time frame as a tool of flexibility**

  For the accumulation model a time frame of 100 and 200 years was chosen to demonstrate scenarios which may be considered a "ceiling situation" and lead to additional precautionary strategies, so as to stay well within the assumed soil limit values.

- **Soil horizon and density**

  30 cm; ρ = 1.5 g cm^{-3} (4,500 Mg ha^{-1})

- **Background value soil as base line for the accumulation of PTEs in the soil**

  Mean values of sand and clay soils of the country surveys from DK, FR and DE;

- **Yearly compost application**

Limiting factor is a *yearly P_2O_5* load of 60 Kg $ha^{-1}y^{-1}$ based on a mean compost concentration of 0.65 % d.m.. This results in an application rate of 9.2 Mg d.m. $ha^{-1}y^{-1}$.

At a mean *organic carbon* concentration in Compost of 20.8 % C_{org}, 9.2 t d.m. compost $ha^{-1}y^{-1}$ result in a yearly input of 1,920 Kg C_{org} $ha^{-1}y^{-1}$. This figure balances mean Carbon losses from arable land (Scheffer and Schachtschabel, 1998).

In the case of *nitrogen* an important question is the beneficial effect of compost application as far as the N supply and efficiency is concerned. It is well documented that N availability of the mainly organically bound compost N pool is available to a very low degree. (Amlinger et al., 2003; Nortcliff and Amlinger, 2003; Amlinger and Götz, 1999). N-efficiency is reported as 0 to 15 % of the initial N input by compost in the year of application (Zwart, 2003; Berner et al., 1995).

The potential N supply from compost at the quantity derived from the maximum P_2O_5 load of 60 Kg ha^{-1} may range between 100 and 180 Kg assuming typical N concentrations in compost. Therefore compost N will not be a limiting parameter.

- **Taking into account mineralisation of compost organic matter when incorporated in soil**

Some authors calculated that up to 8 % of the organic carbon applied with compost would remain in the soil on a mid to long-term basis (Bannick et al., 2002; Smith et al. 2001[FA390]). Respecting a more careful approach towards a reliable accumulation scenario for PTEs we assume 6 % retainment of the total organic matter (OM) which accumulate together with the mineral substance applied with compost over the years. At an estimated OM level of 36 % d.m. this equals a mineralisation rate of 30 % relative to the total dry matter mass. In other words 70 % of the total dry matter would remain in the soil. This accounts for the resulting accumulation of the PTE concentration in the compost on dry matter basis. Accordingly, the increase of soil mass was set to 70 % of the annually added compost dry matter mass. Therefore the calculation is always related to the soil mass at the assumed soil depth (20 or 30 cm) plus 70 % of the yearly applied compost mass. That is 6.44 t in case of a yearly compost application of 9.2 t $ha^{-1}y^{-1}$.

TABLE 3-31: ASSUMPTION FOR ACCUMULATION SCENARIOS FOR HEAVY METALS

			Cd	Cr	Cu	Hg	Ni	Pb	Zn
Atmospheric deposition	(1)	$g\ ha^{-1}\ y^{-1}$	2.315	15.2	87.45	0	44.9	59	332.6
Export									
Export via leaching	(2)	$g\ ha^{-1}\ y^{-1}$	- 0.28	- 9.2	- 8	- 0.28	- 17.8	- 0.56	- 38
Export via harvest	(3)	$g\ ha^{-1}\ y^{-1}$	- 0.67	- 5.27	- 33.92	---	- 10.29	- 5.92	- 172.9
Total export		$g\ ha^{-1}\ y^{-1}$	- 0.95	- 14.47	- 41.92	- 0.28	- 28.09	- 6.48	- 210.9
Background value soil as base line for the accumulation of PTEs in the soil									
sandy soils	(4)	$mg\ Kg^{-1}dm$	0.13	7.65	7.27	0.04	6.6	17.57	26.9
clay soils	(4)	$mg\ Kg^{-1}dm$	0.27	22.45	16.2	0.06	22.53	24.83	61.57
Heavy metal concentration in compost									
Weighted median BWC	(5)	$mg\ Kg^{-1}dm$	0.50	23.0	45.1	0.14	14.1	49.6	183
Weighted 90%ile BWC	(6)	$mg\ Kg^{-1}dm$	0.87	39.9	73.9	0.30	27.0	87.6	276
Quantity of compost per ha and year applied									
		P_2O_5 compost: 0.65 % d.m.		max. **60 Kg P_2O_5 ha^{-1} y^{-1} → 9.2 Mg d.m. compost ha^{-1}**					
Soil depths and density		soil density: 1,5 g cm^{-3}					30 cm; → **4,500 Mg ha^{-1}**		
Time frame for the accumulation model									**200 years**

(1) taken from the latest investigations on the atmospheric deposition of PTEs in the east and south part of Austria from 10 locations (Böhm & Roth, 2000[FA391] and 2001[FA392])

(2) average total export of heavy metals via leachate water (at a percolation rate of 200 mm) taken from figures in Germany (Bannick et al., 2001[FA393]):

Concentration in the leachate water [µg l^{-1}]	Cd	Cr	Cu	Hg	Ni	Pb	Zn
	0.14	4.6	4	0.14	8.9	0.28	19

(3) average total export of heavy metals via harvest (cereals, maize, sugar beet, potatoes) taken from figures in Germany (Bannick et al., 2001[FA394])

(4) mean values of sand and clay soils of the country surveys from DK, FR and DE; see also Table 3–3 in chapter 3; latest Version of the report "Trace elements and organic matter content of European soils" are available on the web page http://europa.eu.int/comm/environment/waste/sludge/index.htm

(5) average of median (mean) values from compost surveys (*biowaste composts*) in seven European countries

(6) average of 90th percentile values from compost surveys (*biowaste composts*) in seven European countries

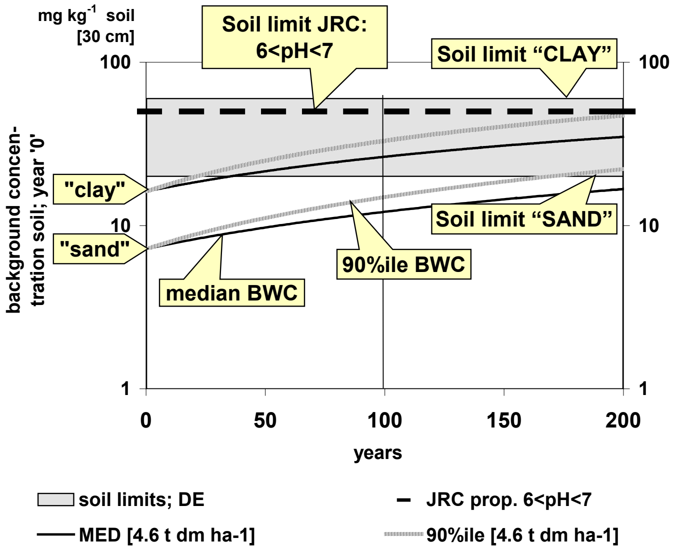
Figure 3-26 shows the accumulation curve for seven PTEs. The amount of annual compost applications – as calculated by limit P loads – is 9.2 Mg d.m. ha^{-1}.

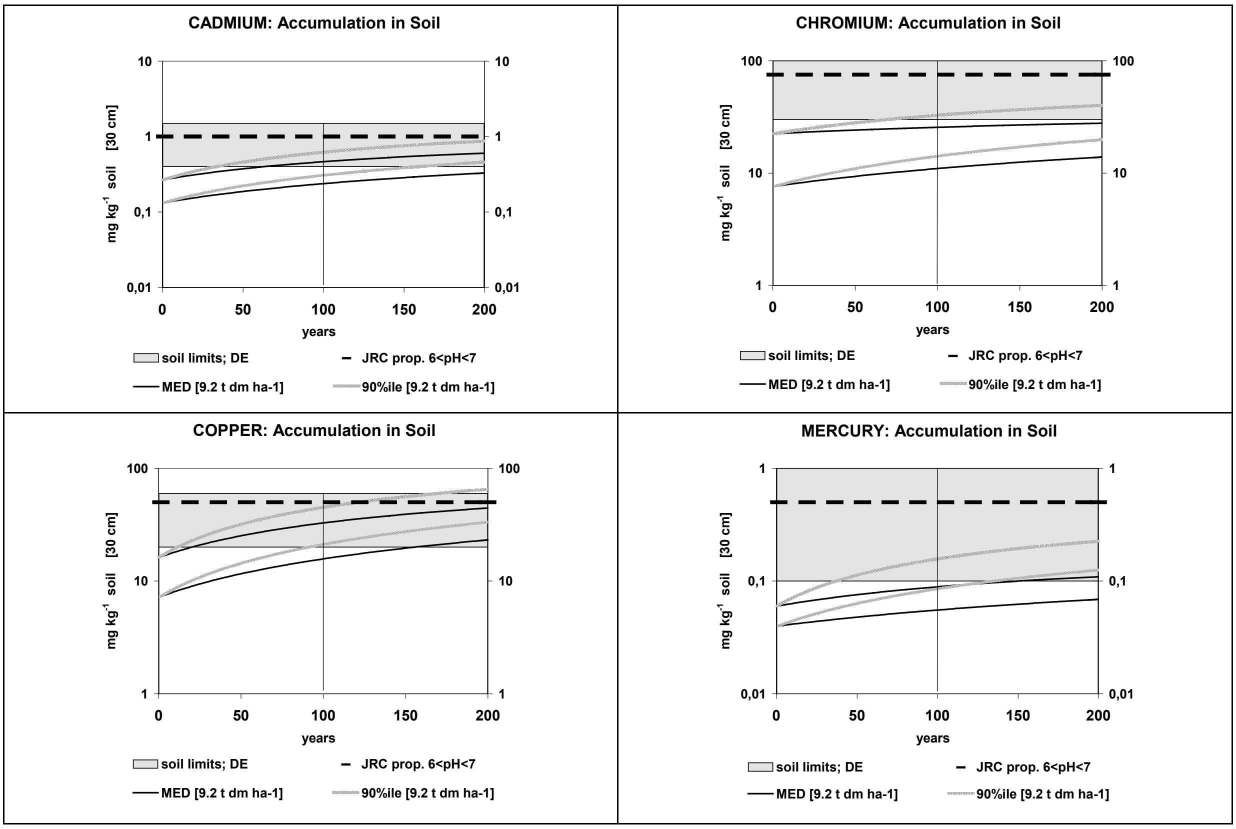
The time frame is 200 years. From the computation of accumulation in a certain soil layer it is evident that the graph is not linear and it would approach an asymptotic curve in relation to the element concentration in compost, taking into account the site and management specific long-term mineralisation rate of the compost.

The lower and the higher starting point (background concentrations) of the accumulation graphs represent sandy and clay soil background values. Accordingly, the lower threshold value (Soil limit "SAND") refers to the graphs **"sand"** and the upper threshold of the shaded range (Soil limit "CLAY") refers to the graphs **"clay"** (see Table 3-31).

The two PTE concentration levels (weighted median and 90th percentile) were computed for each of the soil types ("sand" and "clay")

Example graph:





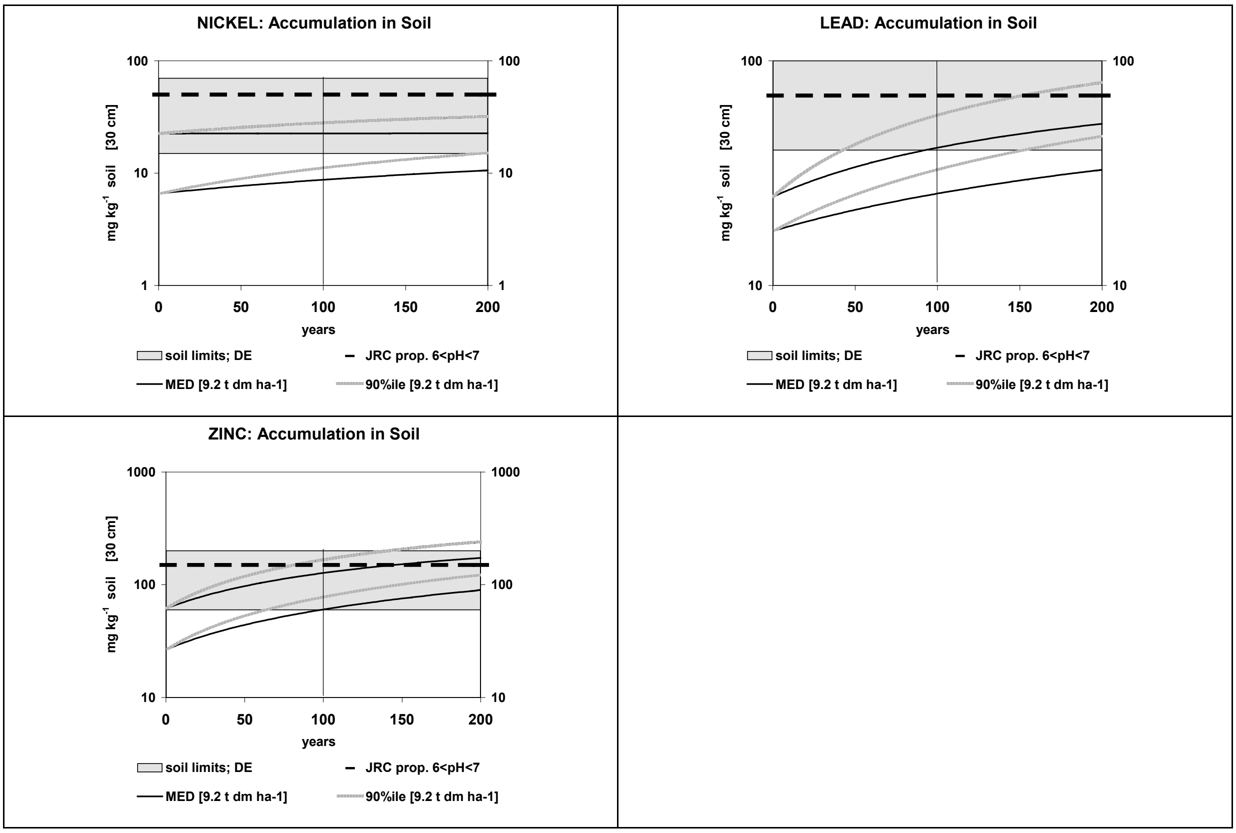


FIGURE 3-26: ACCUMULATION SCENARIOS FOR HEAVY METALS WITH MEDIAN AND 90TH PERCENTILE PTE CONCENTRATIONS IN EUROPEAN COMPOSTS

3.7.3.3 Results of accumulation scenarios

- Chromium will not reach the soil limits under any of the assumed scenarios.
- In the case clay soils, soil threshold values – with the exception of Zn – will not be exceeded within to 200 years of compost application.
- If it is assumed that target values of sandy soils must not be exceeded within 100 years, allowable PTE concentrations could – with the exception of Zn – be even higher than the median values of European BWC. This is valid even if 9.2 Mg compost per ha and year are applied.
- Cu and Zn concentrations which would exceed the 90th percentile significantly might require a site specific evaluation on sandy soils if such composts are to be used continuously in the long run.

3.7.3.4 Concept of limit values for an European regulation

Limit values for composts, intended for the use in food and fodder production make sense only if they do not set unreasonably high standards for compost qualities.

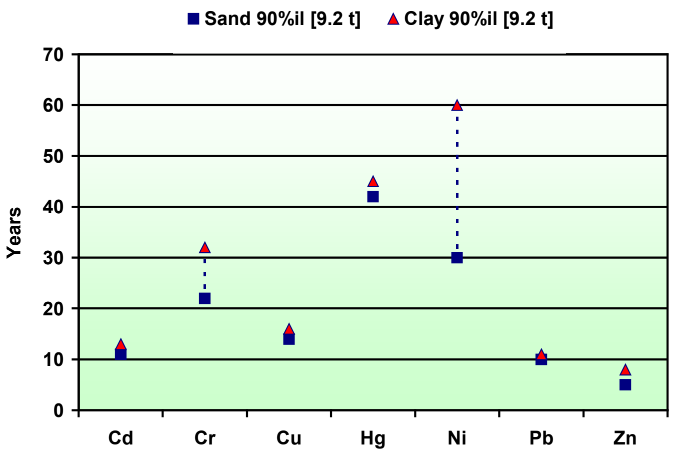
On the other hand they have to fulfil the task of minimising risks to the environment while taking into account the agronomic needs for the benefits of soil-plant system.

Regarding temporal and regional variations as well as the variation within an individual composting plant, setting a tolerance factor in addition to the calculated 90th percentile value of European biowaste composts would be a reasonable way feasible.

In Germany, the seasonal coefficient of variation in composting plants averages 28% and ranges up to 50-60% (Kranert, 2002[FA395]; see also chapter 4). In addition, unavoidable deviations of incremental samples within one compost batch range between ±30 and ±40 % from the mean value. The highest individual variations were found for Cd (100 %) and Lead (73 %) (Breuer et al., 1997; see chapter 7.4.2)

Comparing the statistically weighted 90th percentiles on EU level to two countries in the starting phase of source separation, Spain and the UK, the PTE concentration of the latter is increased by 7 % (Cr) to 56 % (Ni).

Based on these considerations a 50 % tolerance is added to the 90th percentile value of European BWC and the averaged 90th percentile of ES and UK composts. These concentration values are named [level 1] and [level 2] respectively.



	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Start soil* sand clay	0,13 0,27	7,65 22,5	7,27 16,2	0,04 0,06	6,6 22,5	17,6 24,8	26,9 61,6
minimum measurable increase	0.02	1.5	2.0	0.02	1.5	1.5	2.5
90%il conc, in compost	0,87	39,9	73,9	0,30	27	87,5	276

* Background concentration in sand and clay soil in year '0'
application rate: 9.2 Mg compost d.m. $ha^{-1}y^{-1}$

FIGURE 3-27: PERIOD OF TIME FOR MEASURABLE INCREASE OF HEAVY METAL CONCENTRATION IN THE SOIL

Figure 3-27 demonstrates the period until an analytical detectable increase may be measured when compost of a certain quality is applied. As a precaution, the heavy metal concentrations assumed are the 90th percentile of the European BWC. Depending on the *distance* from background levels of the soil (*"sand"* and *"clay"*), an increase in heavy metal contents in soil to an analytically detectable extent may be expected within a period of 5 (Zn) to 60 (Hg) years.

Table 3-32 gives a comparison of the resulting concentrations with the proposed limit values of the Working Document "Biological treatment of biowaste" (2nd draft) and the averaged limit values for BWC in European countries.

TABLE 3-32: KONZEPT FOR HEAVY METAL LIMIT CONCENTRATIONS FOR A EUROPEAN BIOWASTE AND COMPOST PROVISION (MG KG^{-1} D.M.)

			Cd	Cr	Cu	Hg	Ni	Pb	Zn
Weighed median/mean in biowaste compost in the EU	(1)	mg Kg^{-1}dm	0.50	23.0	45.1	0.14	14.1	49.6	183
90%ile EU + 50 % [level 1]	**(2)**		**1.3**	**60**	**110**	**0.45**	**40**	**130**	**400**
Warranty values – Means on plant scale	(3)		*1.1*	*70*	*110*	*0,5*	*60*	*120*	*380*
90%ile UK&ES + 50 % [level 2]	**(4)**		**1,9**	**64**	**170**	**0,65**	**63**	**200**	**470**
Warranty values – Single measurements on plant scale	(5)		*1.8*	*100*	*180*	*1.1*	*80*	*190*	*530*

(1) average of median (mean) values from compost surveys (biowaste composts) in seven European countries.

(2) average of 90th percentile values from compost surveys (biowaste composts) in seven European countries + 50 % tolerance.

(3) Warranty values calculated on the basis of 376 Composting facilities in the average of 4 subsequent measurements at a precision of $p < 0.05$ (Reinhold, 2003)

(4) average of 90th percentile values from compost surveys (biowaste composts) in UK and Spain (Catalonia) + 50 % tolerance.

(5) Warranty values calculated on the basis of 376 Composting facilities for individual samples at a precision of $p < 0.05$ (Reinhold, 2003)

3.7.4 Heavy metal mobility as influenced by compost application – examples from literature

Following Timmermann et al. (2003[SP396]) a positive heavy metal balance in compost application systems cant be avoided even at optimum organic fertilisation rates. The metal inputs cannot be compensated by plant uptake and leaching (Poletschny, 1995[SP397]; Wilcke & Döhler, 1995[SP398]). Specifically this is the case for Pb, Cr, Ni and Cd (mean output by harvest <10 % of input), and to a less extent for Hg, Cu und Zn (mean output by harvest 10 - 30 % of input). The positive balance can be minimised considerably by

- use of high quality composts with low heavy metal concentration
- lowering compost rates
- increasing output rates (crop rotations with high take-up rates and complete utilisation and removal of harvest and crop residues)

The authors conclude that quality and of harvested food crops are not endangered by heavy metal inputs from compost if food practice of compost fertilisation is respected.

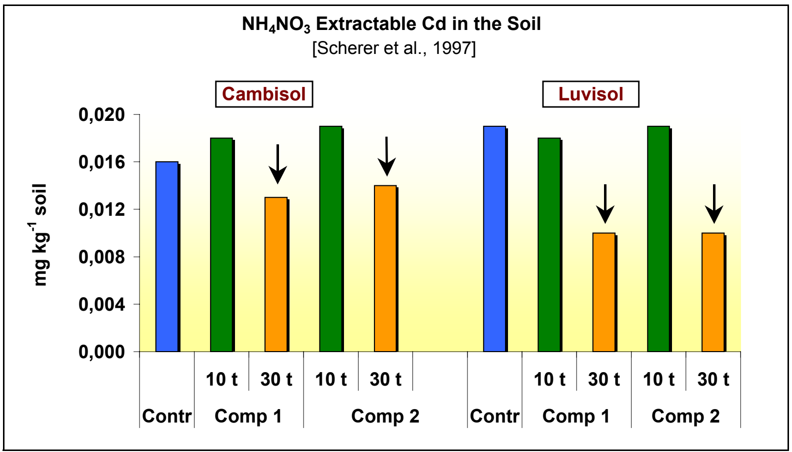


FIGURE 3-28: SIGNIFIKANT REDUKTION DES NH_4NO_3-LÖSLICHEN CADMIUMS AN ZWEI MIT KOMPOST GEDÜNGTEN STANDORTEN

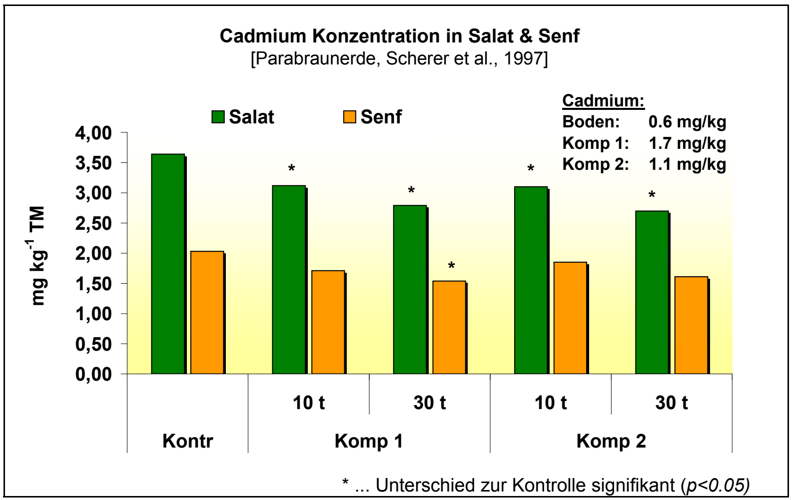
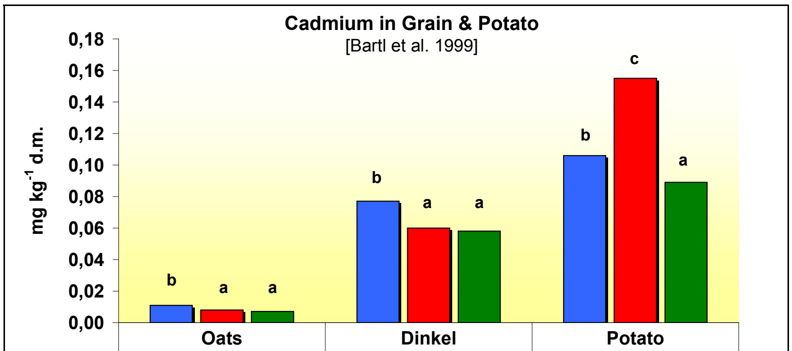


FIGURE 3-29:. CD KONZENTRATION IN IN SALAT UND SENFPFLANZEN NACH KOMPOSTAPPLIKATION IM TOPFVERSUCH (PARABRAUNERDE; 2 KOMPOSTE; 10 UND 30 MG KOMPOST HA^{-1})



	Oats	Dinkel	Potato
0	0,011	0,077	0,106
N3	0,008	0,06	0,155
BWC3	0,007	0,058	0,089

difference significant where differing letters (*p*<0,05)

CONTROL (0 - FERTILISATION) A MINERAL FERTILISED SYSTEM (N3) AND A COMPOST PLOT (BWC3; MEAN DOSAGE: CA. 32 MG HA^{-1} Y^{-1} IN 6 YEARS)

FIGURE 3-30: CADMIUM IN THE GRAIN OF OATS, DINKEL AND POTATOS

The example of Figure 3-28 may be given to demonstrate that the exchangeable or soluble part of metals can be reduced in compost amended soils. In a pot experiment it could be shown that even at a rate of 30 tons compost per ha in a Cambisol and Luvisol respectively the amount of Cd extractable in NH_4NO_3 was reduced significantly (Scherer et al. 1997). At the same time the Cd uptake by the crops (statistically significant for lettuce at both application rates and with two composts) were decreased (Figure 3-29).

The result of another field experiment is shown in Figure 3-30. After 6 years of continuous compost application (loamy silt; 6 repetitions; ca. 32 Mg $ha^{-1}y^{-1}$) the Cd content in potatoes was significantly lower than in the control and the mineral fertilised plots. The Cd concentration in the mineral fertilised variants was assumed to be related to the use of the Cd containing phosphorus fertiliser *super–phos* (Bartl et al., 1999). These results may support the hypothesis that the application of high quality compost contributes to the enhancement of active surfaces and thus meliorating the sorption capacity and strength for heavy metals.

In the framework of the symposium *Applying compost – Benefits and Needs"* (Amlinger 2003) further examples from experimental experience were presented.

In field tests for compost application over several years, which are carried out since 1995 in Baden-Wuerttemberg (Germany) on six field locations, the heavy metal contents of the harvest products after 6 years remained unaffected by the compost application.

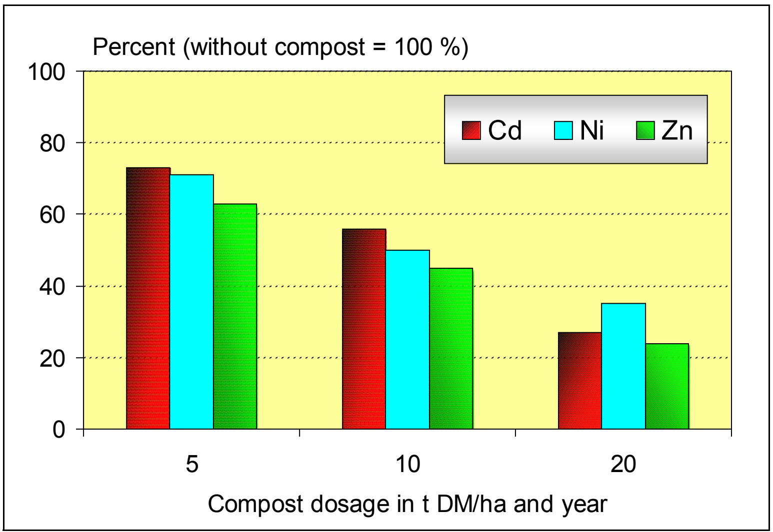


FIGURE 3-31: MOBILE HEAVY METAL CONTENTS (SOIL EXTRACTION WITH 1M NH_4NO_3) OF SOILS IN RELATION TO COMPOST DOSAGE (AFTER 6 YEARS) [IN % OF UNFERTILISED CONTROL); KLUGE (2003)

The very small heavy metal uptake of the harvest products amounts to max. 10 - 15 % of the heavy metal supply with composts. As a result the total contents in soil were not raised. The mobile heavy metal contents of Cd, Ni and Zn even decreased with rising application of com-posts (Figure 3-31). According to these results an increase in heavy metal contents in soil to an analytically measurable extent even in medium-term periods of 10 - 20 years is not to be expected.

Organic matter (specifically complex polymer humic substances) in compost are absorbed by the soil matrix. Thus compost amendments alter the entire sorption and exchange dynamic for metals.

Figure 3-32 und Figure 3-33 show sorption isotherms for Zinc and Cadmium in untreated and repeatedly sludge treated soil (Petruzzelli & Pezzarossa, 2003).

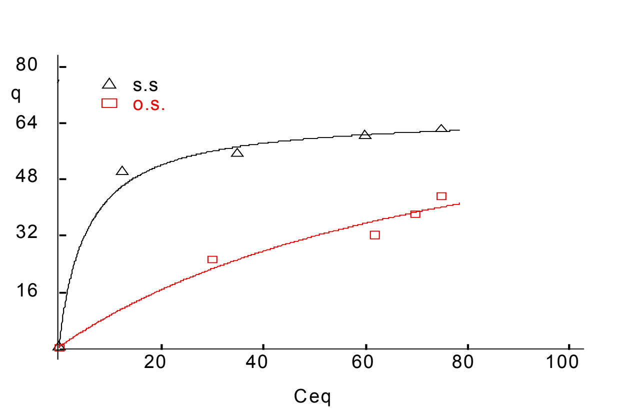


FIGURE 3-32: SORPTION ISOTHERMS OF ZINC IN ORIGINAL (O.S.) AND SLUDGE TREATED (S.S.) SOIL (PETRUZZELLI & PEZZAROSSA, 2003)

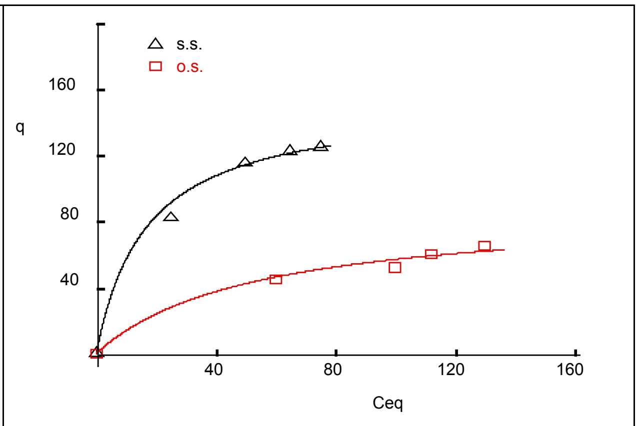


FIGURE 3-33: SORPTION ISOTHERMS OF CADMIUM IN ORIGINAL (O.S.) AND SLUDGE TREATED (S.S.) SOIL (PETRUZZELLI & PEZZAROSSA, 2003)

The absorption capacity for the investigated metals increased in soil treated with composted sludge. The degree of the amount adsorbed increased of more than 75% for zinc and more than 27% for cadmium.

It is important to stress that since the soil sorption capacity is inversely related to the amount of metal absorbed, low-metal biomasses (*'clean compost'*) are more suitable to provide new absorbing sites.

This fact alone demands the production of compost processed from source separated organic materials of high quality.

This protective effect can be mainly due to the added organic matter and can be considered effective even for a long time after the cessation of compost addition. The half-life of decomposition of organic matter in soil has been estimated to be about 10 years (Bell et al., 1991).

Also inorganic materials contained in the compost as carbonates, oxides, and phosphates, are known to be able to retain metals in relatively insoluble forms (Brown 1998). The inorganic component is an important fraction of biowaste, which does not decrease with time, and can positively contribute to reduce phyto-availability of trace metals.

As indicated, ion sorption and exchange processes depend – among others - of pH, cation exchange capacity (CEC) and the existence of reactive surfaces. Compost increase the buffer capacity and absorption efficiency of soil also because this properties are enhanced by the alkaline effective substances of compost

A key question is if there is a link between compost maturity and solubility of heavy metals. Leita et al. (2003) investigated the portion of disolvable organic carbon (DOC) during composting and the extractability of heavy metals connected therewith. The $CaCl_2$- extractable DOC already decreased mainly during the first rotting stage from 3.5% finally to 0.5% at the end of the mesophilic maturation phase. This observation has been made also by other authors (Chen and Inbar, 1993, Chefetz et al., 1996, Kaschl et al., 2002). The highest metal concentrations extractable in $CaCl_2$ can be found in the first week of composting in a still acidic milieu. It is the soluble Cd and Zn which significantly decrease with proceeding rotting (Figure 3-34).

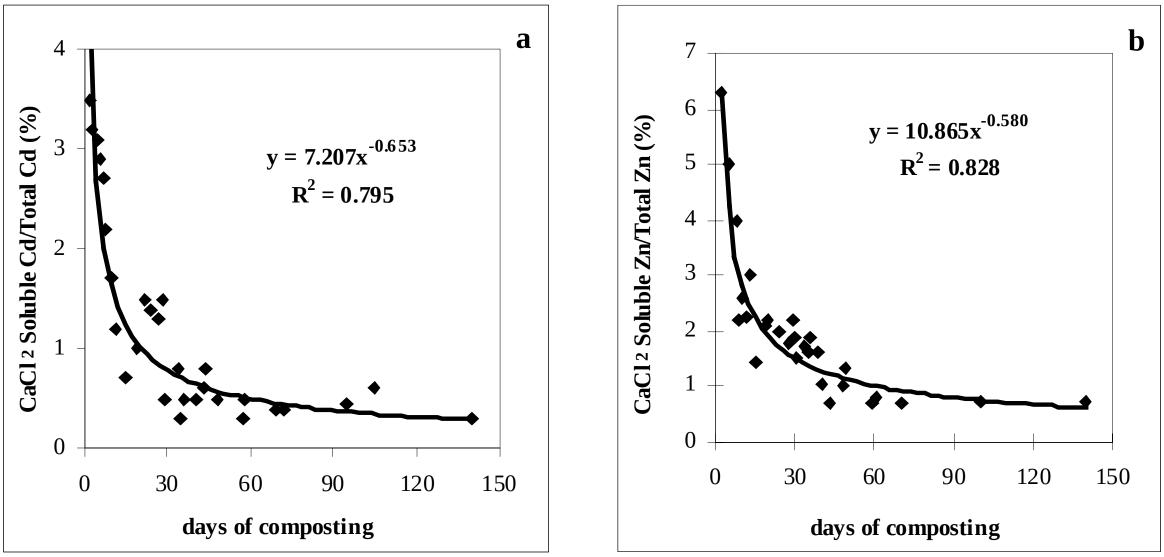


FIGURE 3-34: SOLUBLE FRACTION OF CD (A) AND ZN (B) DURING COMPOSTING (LEITA ET AL., 2003) .

In addition the $CaCl_2$- extractable Cd and Zn correlated strongly only with non-humic substances identified in DOC.

It can be concluded that during the rotting process maturation (humification) determines the heavy metal mobility. The most important chemical process herein is complexation.

3.7.5 Effect of compost application systems on the heavy metal concentration in soils, mobility and take up by plants – tabular survey

TABLE 3-33: RESULTS FROM LITERATURE REGARDING THE EFFECTS OF COMPOST ON THE HEAVYMETAL CONTENT IN SOILS AND PLANTS.

	Impact on Soil			Impact on Plant		
Fieldtrials						
Authors	↑	↓	—	↑	↓	—
Baldwin & Shelton, 1999[SP399]	Zn, Cd, Ni					Pb, Ni
Bartl et al., 1999[SP400]	Pb		Ni, Cd			HM
Boisch, 1997[SP401]	Cd, V, Cu und Zn (leaching)					
Bragato et al., 1998[SP402]			Zn, Cu, Ni, Pb (total)			
Breslin, 1999[SP403]	Zn, Cd, Pb Cd (leaching)					
Buchgraber, 2000[SP404]			Pb, Ni, Cd			
Businelli et al., 1996	Cu, Pb, Zn					
Cortellini et al., 1996[SP405]	Zn, Ni			Zn, Cu		
Cuevas et al., 2000[SP406]	Cu, Zn, Pb					
Gigliotti et al., 1996[SP407]	Cu, Zn, Pb, Cr					
Gäth, 1998[SP408]	SM			Pb, Zn		
Hartl et al., 2003[SP409]	In spite of higher abs. Cd-input (Compost)	Cd immobilisation			Cd	
HDRA Consultants, 1999[SP410]			Zn, Cd, Cr, Cu, Pb, Ni			
Leita et al., 1999[SP411]	Cd, Cu, Ni, Zn					
Moreno et al., 1996[SP412]	Cd, Zn			Cd, Zn		Ni, Cu
Peverly & Gates, 1994[SP413]	Zn, Ni			Ni, Cu		
Pinamonti, 1998[SP414]	Zn (DTPA) Zn, Ni, Pb, Cd, Cr (total)			Ni, Cd, Cr (BWC)		Ni, Pb, Cd, Cr (SSC)
Timmermann et al., 2003[SP415]	Cu (mobile content)	Cd, Ni, Zn (mobile content)	Pb (Cr) (mobile content)			
Vogtmann et al., 1996[SP416]		Cd (compare control)	Cd, Zn		HM	
Weissteiner, 2001[SP417]	Zn					
Vessel resp. Incubationexperiments						
Scherer et al., 1997[SP418]				Pb, Cd		Zn
Shuman, 1998[SP419]		Pb, Cd (availability)				
Shuman, 1999[SP420]	Zn (non exchangable fraktion)	Zn (exchangable fraktion)				
Warman et al., 1995				Cd, Cr,Hg		Zn, Cu, Ni, Pb

↑ ... increased values; ↓... decreased values; — no tendency detectable
HM ... Heavy Metals general; BWC ... Biowaste compost; SSC ... Sewage sludge compost

TABLE 3-34: EFFECT ON HEAVY METAL CONCENTRATION IN SOILS, MOBILITY AND TAKE UP BY PLANTS – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Effects on Heavymetal Content in Soils and Plants				
Baldwin & Shelton, 1999[SP421]	Field trial, 2 years, Nicotiana tabacum cultivated in 1994 and 1995; claysoil with and without lining, soil- and leafsamples 3x per year	BWC, SSC and blend 1994: 0, 25, 50 and 100 Mg Comp ha^{-1}; 0 and 4000 Kg lime; 224 Kg N, 56 Kg P; 1995: only lime, N and P	Soil: linear increase of DTPA-extractable Zn, Cd and Cu with higher application rates. No influence of the pH-value on extractable metals, also not with high metal contents of Comp. Plant: with the exception of Cd, 1994 no Cd, Ni and Pb-content detectable in leaves. No influence of oH on Cu- and Zn-concentrations in leaves.	soil: Zn, Cd, Cu ↑ plant: Pb, Ni no influence
Bartl et al., 1999[SP422]	Field trial, 1992 – 1998 grey alluvial soil, sandy to loamy silt, pH 7,6; analyses of the harvest $1996^{-1}998$ (O, Sp, Pot). Latin rectangle, 6 replications.	12 fertilisation variations with BWC +/- min. N-supplementation, $1992^{-1}998$ Here only 3 var. evaluated: BWC ($1992^{-1}998$): 30 – 60t f.m. ha^{-1} for the years 1992-98 ; NPK; „0“	Soil: after 6 years no accumulation of Ni and Cd through Comp application, but of Pb. Plant: yield crops: Pb not detectable (detection limit of 0,1 mg/Kg). No raised Cd-content in plants. Oats and spelt showed the highest Cd-concentrations in grains of control.	soil: Pb ↑; Ni and Cd no influence; plant: no influence
Boisch, 1997[SP423]	Field trial, (1991 – 1994),: 6 trial sites: sandy brown soil (conv., Sil-M; Sluc, N / P min. als initiation dose; pseudogley-gley, pseudogley-lessivé (conv. Ra-W-W – W-W); c) gley-pseudogley (Ra – W-Bar – W-Bar, min.) d) sandy ground moraine, sandy brown soil (ecolog. Pot – S-R- O – SW).	BWC: 6 to 16t d.m. ha^{-1}, according to demand, resp. 32 Mg d.m. ha^{-1} as amelioration fertilisation on light sites, control (on ecolog. cultivated plots unfertilized);	No difference in nutrient - and toxin-load of plants between different fertilisation variations. Toxin extraction of plants < Comp loads. Toxin loads, except for Cd, above the ones from NPK. The loads of Cu and Zn from Comp were comparable with the ones from Slu. Only with Pb an increased accumulation potential is assumed. In the leachate of sites with low humus content and low pH-values slightly raised concentrations of Cd, Cu, V and Zn were found in connection with Comp applications. Application intervals of several years are a possibility for argillaceous and loamy soils, sandy soils should be fertilized annually.	Boden: Cd, V, Cu, Zn slightly increased leaching loss
Bragato et al., 1998[SP424]	Field trial, silty loam, 5 years after application DTPA-extractable metals, analysis of Corg in soil and C of the mikrobial biomass (MBC)	Since 1989 annually 7,5 resp. 15 Mg ha^{-1} concentrated resp. concentrated and composted Slu	Soil: after 5 years no sign. change in total-heavymetal content Zn, Cu, Ni, Pb (high plant extraction?) between variations. DTPA-extractable Zn correlated with MWC.	Soil: no influence from diff. variations

Authors	Experimental Design	Fertilisation	Results	Remarks
Breslin, 1999[SP425]	Field trial, 52 months, sandy loam, pH 5,6 – 6,4, SOM 2,8 %; nutrient leaching of As, Cu, Fe, Pb, Zn	BWC and BWC with Slu, 21 – 62 Mg ha^{-1}, HM 3-20 times higher concentration than in soil.	Cu, Pb and Zn remain in the top 5 cm within 52 months, Cd leaches out. Accumulation of Zn, Cd and Pb relative to surroundings is proportional to application rate.	soil: Zn, Cd, Pb ↑; leaching of Cd
Buchgraber, 2000[SP426]	Field trial, 5 years, 6 sites (1 pasture), pH >6	BWK, MC, gr.BWK, HM-content within range of quality ,Pb, Ni and Cd in BWC clearly higher than in MC.	Extraction through plants are assumed to be minor, no detection through soil analysis.	soil: Pb, Ni, Cd no influence
Businelli et al., 1996[SP427]	Field trial, 6 years, M monoculture; random. block; 4 replications; argillaceous loam, pH 8,3; Corg 0,76%,	MWC, 25 – 30 cm incorporated, 1) 30 and 90 Mg f.m. ha^{-1} and year 2) 30 Mg ha^{-1} during 1st and 4th Jahr each, min. NPK-supplementation 3)control: NPK without Comp	Soil: clear increase of total content of Cu, Pb and Zn after 6 years. EDTA extracted HM (extracts instable chem. fractions) increase even more clearly. Cd, Cr, Ni stayed the same in Comp fertilzed sites and control. No change detectable below 40 cm (high pH, minimal mobility, etc.). plants: (roots, grain, stem, leaves) at 90 Mg ha^{-1} generally sign. higher for the metals: Cu, Pb, and Zn, but not for Cd, Cr and Ni.	soil Cu, Pb, Zn ↑ (total and EDTA) up to 40 cm plants Cu, Pb, Zn ↑, Cd, Cr, Ni no influence
Cortellini et al., 1996[SP428]	Field trial, 6 years, silty loam, CR: W-W, SB, M; Sil-M in plants and soil, OM, Ntot and available P in soil	SSC + St, liquid and concentrated anaerobically treated SSC (7,5 and 15 Mg d.m. ha^{-1} and year); NPK	Sign. increase of Zn in grain and roots and of Cu in SB-roots, but not of Cd, Cr, Ni, Pb. No influence of application rates. Slu caused a higher accumulation than dehydrated Slu and Comp. After 6 years increase in SOM, Ntot, available P, extractable Zn and Ni, according to application rate.	
Cuevas et al., 2000[SP429]	Field trial, thin vegetation cover, degraded, semiarid soil, randomised block, 4 replications, soil analysis 1 year after compost application	BWC 0, 40, 80, 120 Mg ha^{-1},	Increase of all HM-concentrations, sign. only with Zn, Pb and Cu at medium and high application rates.	
Gigliotti et al., 1996[SP430]	Field trial and greenhouse, argillaceous loamy calcareous soil, pH 8,3, M	BWC, 6 years 90 Mg ha^{-1} and Jahr, 540 Mg in total	Sign. increase in HM-content in soil only with Cu, Zn, Pb and Cr (only during the last two trial years), M: higher uptake rates: Pb 3x as high, other HM twice as high as control.	soil: Cu, Zn, Pb, Cr ↑ plant: Pb and other HM ↑
Gäth, 1998[SP431]	Field trial 1976 – 1989, brown soil from basaltweathering,	MWC-applications in 13 years, amounts: 0 , 40 Mg d.m. ha^{-1} (=	The HM-enrichment beyond application and extraction is detectable in top soil, at an error rate of max. 10%. The	soil: HM ↑ plant: Pb and Zn

Authors	Experimental Design	Fertilisation	Results	Remarks
	CR: SW – W-W - O	218 Kg Pb and 196 Kg Zn ha^{-1}), 80 Mg d.m. ha^{-1}, 120 Mg d.m. ha^{-1}.	enrichment causes an increase of Pb- and Zn-concentrations in grains and with Zn a slow leaching.	↑
HDRA Consultants, 1999[SP432]	HDRA-Research Grounds: sandy loam, organic, CR: Pot-onions -Ca-carrot - grass/clover	3 different GWC, 250 Kg N ha^{-1}, x2 and x3, f.m., poultry manure, Slu	After 2 applications no sign. change if Zn, Cd, Cr, Cu, Pb and Ni-content in soil.	soil: Zn, Cd, Cr, Cu, Pb, Ni no influence
HDRA Consultants, 1999[SP433]	Shepton Farms Ltd.; 7 sites; loam, clay and limestone; organic cultivation, diverse CR	GWC 30 Mg ha^{-1} (=250 Kg N ha^{-1})	After 3 applications no sign. change of HM-content in soil.	soil: no influence of HM
HDRA Consultants, 1999[SP434]	Staple Farm, heavy loam, conventional; CR: W-W – W-Bar - Ra	GWC, 4 variations: no Comp + customary fertilisation; low amounts of Comp (302 Kg N ha^{-1}) + low amounts of NPK; much Comp (605 Kg N ha^{-1}); much Comp (605 Kg N ha^{-1}) + low NPK	No sign. change of HM-content in soil.	soil: no influence of HM
Kluge et al., 1997[SP435]	Field trial, since 1995, lS, uL, sL, uL	12 BWC and GWC, 0, 50, 100, 200 % of GAP, 10 Mg ha^{-1} d.m. in „optimalvariation“	HM-load clearly below limits, according to Comp regulations of Baden-Württemberg, balance of application and extraction clearly positive, mobile Pb, Cd, Ni and Zn-content decrease initially.	Total content barely affected
Leita et al., 1999[SP436]	Field trial, sandy loam, longterm effect (12 years) of compost in comparison to NPK and MC on TOC, microbial biomass C, B_c und metabolic quotient qCO_2 as well as heavy metal availability.	BWC: 500, 1000 and 1500 Kg $ha^{-1}year^{-1}$ = 2, 4 and 6-fold of Italian limit value.	HM total load: Cd, Cu, Ni, Pb, Zn below EU-limits; DTPA-extractable Cd, Cu, Ni, Zn similar on control and NPK-sites, increase on organically fertilized plots (dependent on Corg-input).	soil: Cd, Cu, Ni, Zn ↑

Authors	Experimental Design	Fertilisation	Results	Remarks
Moreno et al., 1996[SP437]	Field trial, silty loam, pH 8,77, Bar	SSC 20 and 80 Mg ha^{-1}, normal (2 mg/Kg Cd), once contaminated with Cd (760 mg/Kg Cd), once contaminated with Cd (830 mg/Kg), Zn (1640 mg/Kg), Cu (995 mg/Kg), Ni (525 mg/Kg)	The addition of highly contaminated Comp (mainly Cd) cause yield-depression for grains, but not straw. Cd and Zn were easily absorbed by Bar. Ni and especially Cu were complexed by SOM and not plant-absorbed. Plants on Comp plots higher N- and P-content than control. Cd and Zn-loads in soil correlated with plant-content, no correlation with Cu and Ni.	plant: Cd, Zn ↑, Ni, Cu so influence soil: Cd, Zn ↑
Moreno et al., 1998[SP438]	Greenhouse, lettuce (4 months) and Bar (months), 4 replications., very low SOM-content, container with 20kg soil, HM-content, SOM-content and enzymatic activity	SSC partially enriched with HM, composted with barley-St, 20 and 80 Mg ha^{-1}, control: soil without Comp, customary NPK-fertilisation	Yield: lettuce: Comp plot below control, Bar: higher yield only with high uncontaminated SSC-application. High content of Cd, Cu, Ni and Zn inhibited protease-BAA-activity in comparison to other Comp. Influence on phosphatase- and ß-Glucosidase-activity.	Cd, Cu, Ni, Zn influence enzymatic activity
Peverly & Gates, 1994[SP439]	Field trial, sludgy, argillaceous loam, M, 2 years	BWC (318 mg/Kg Pb) with Slu and woodchips, 46, 92 and 184 mg ha^{-1} before planting	No toxic effects of Comp on germination and growth of M. Metal- and nutrient concentrations of plants barely affected, K, Ni and Cu-content increased in comparison to control. Raised Zn and Ni-load of soil limited to topsoil and had no effect on yield or grain- and water-quality.	plant: HM-content barely influenced; Ni, Cu ↑ soil: Zn, Ni ↑ in topsoil
Petruzelli, 1996[SP440]	Theory		Influence of feedstock! Source separation highly important! In Comp with low HM-concentrations the bio-availability of HM is ‚controlled' by Comp chemistry.	

Authors	Experimental Design	Fertilisation	Results	Remarks
Pinamonti, 1998[SP441]	Field trial, 6 years, vineyard, calcareous soil, 15 % slope, semidandy, stony	control (500 Kg ha^{-1} NPK), PE(Polyethylen-Mulch), 2 Comp: SSC+bark (660 Kg ha^{-1} organ. N) BWC (530 Kg ha^{-1} organ. N)	SSC causes a sign. increase of total and DTPA-extractable Zn-content in soils. BWC increases total Zn, Ni, Pb, Cd and Cr-content and the DTPA-extractable content of Zn, Ni, Pb, Cd. No influence on Cu. No changes in Zn-concentration of leaves and juice. SSC: no influence in plant uptake of Ni, Pb, Cd, Cr. BWC: sign. increase of Ni and Cd in leaves, Cd and Cr in juice. No phytotoxic symptoms.	soil: Zn (DTPA) ↑; Zn, Ni, Pb, Cd, Cr (total) ↑; Zn, Ni, Pb, Cd (DTPA) ↑; Cu +/– plant: Zn, Ni, Pb, Cd, Cr no influence (SSC), Ni, Cd, Cr ↑ (BWC)
Scherer et al., 1997[SP442]	Vessel experiment, diverse crops (Pb, Cd, Zn). 2 different soils: HM-contaminated soil from Eifel: brown soil from the vicinity of a lead ore deposit, IS-lU, pH 6,4, Pb-content 544 mg/Kg; non contaminted topsoil near Bonn (lessivé from loess), ul, pH 5,9.	2 BWC, without Pb > 600 mg/Kg	Comp caused a decrease of the Pb-content in the above-ground plant parts compared to control, decrease on HM-contaminated soils with higher pH-values more apparent. Lessivé: in comparison to control lower Cd-content of plants, but decrease of Cd-content with brown soils after Comp application less apparent. Influence on Zn-content of plants not homogenous. The Comp application reduced the Pb and Cd-content of the crops in comparison to control on (geogenous-dependent) HM-contaminated brown soils – independently of the HM-content of the applied Comp.	plant: Pb, Cd ↓; Zn no influence
Selivanovskaya et al., 2001[SP443]	Field trial, random. block, 4 replications., Bar, grey forest soil	untreated Slu, anaerobically treated Slu (10 Mg ha^{-1} d.m. each), SSC (30 Mg ha^{-1} TM); control	Sign. HM-increase on all plots in comparison to control, but below European and Russian limits.	
Shuman, 1998[SP444]	Incubation experiment, 5 organic wastes, two soils (coarse and fine texture), distribution of Cd and Pb amongst the soilfractions was analysed.	Commercial Comp (Slu and woodchips), poultrywaste PL, cotton gin litter CL, secondary industrial Slu ISlu, commercial humic acids HA. Blend with soils 30 Mg/a, only PL 5 Mg/a.	The added Cd and Pb were found mainly in the SOM fraction, in spite of the increase of the extractable fraction of the sandy Norfolk soils. SMC and humic acids lowered Pb in the exchangeable fraction of both soils and increased Cd in SOM of the sandy soil. SMC and humic acids decreased Pb in the exchangeable and SOM fraction in the MnO- amorph AfeO and crystallin CfeO-fraction. Addition of PL increased Cd and Pb in the exchangeable fraction of the sandy soil. Some org. additives like SMC lower the Cd- and Pb-availability because of a redistribution of the metals from the SOM fraction into less soluble fractions.	soil: Pb and Cd-availability ↓

Authors	Experimental Design	Fertilisation	Results	Remarks
Shuman, 1999[SP445]	Incubation experiment, distribution of Zn amongst the soilfractions	Commercial Comp (Slu and woodchips), spent mushroom compost SMC, poultrywaste PL, cotton gin litter CL, secondary industrial Slu ISlu, commercial humic acids, with and without 400 mg/Kg Zn.	No Zn-addition → majority of metals in the residual fraction. Comp, PL and Slu increased the Zn-content in all fractions. With Zn-addition the majority of the metals were stored in the exchangeable SOM fraction. SMC and humic acids lowered the Zn-content in the exchangeable fraction and raised it in others. Effects more evident in soils with coarser structure and dominant quarz-fraction, compared to more finely structured soils with a dominant caolinith-fraction in the clay. Org. materials with a high Zn-content may increase concentrations in all fractions, while others like SMC and humic acids may lower the availability (redistribution into less soluble fractions)	*soil*: Zn in exchangable fraction ↓, in others ↑
Timmermann et al., 2003[SP446]	Long-term Comp experiment (8 resp. 5 years): duofactorial split-plot facility with 12 variations at 4 replications. random. → 48 plots per experiment 6 sites : lS, uL, uL, utL, uL, sL CR: M – W-W – W-Bar	Comp application: 0; 5; 10; 20 Mg ha^{-1} N-supplementation level N0: no additional N-application level N1: 50 % of the optimal N-application level N2: 100 % of the optimal N- application on basis of the Nmin-content of the soil as well as further aspects, like preliminary crop etc. (comp. nitrateinformationsservice - NIS).	The Pb, Cd, Cr, Ni and Hg-content – stayed on the same level (even with excessive Comp application rates) as the level of the control. Only Cu and Zn-content were increased slightly, some sign. (1 – 2 mg/Kg), in mean of all trials with excessive Comp application (annually 20t ha^{-1} d.m.), but not with lower and standard agricultural Comp applications (level K1 and K2). The available contents were not affected during the trial period (Pb, Cr) resp. decreased considerably, stat. sign. (Cd, Ni, Zn). Only the mobile Cu-contents increased slowly. With initially regular Comp applications, which were terminated eventually, a gradual remobilization of the initially complexed HM cannot be ruled out. <u>Plant</u>: HM-content of cash-crops, Corn-M resp. Sil-M, remain within the mean of several years of Comp application, mostly uninfluenced. This applies to Pb, Cr and Hg. In comparison to control, slight decrease of Cd, Ni and Zn-content, because of low availability through increased Comp application. Slightly increasing tendency of Cu-content of crops, mainly with Sil-M, because of a minor rise of Cu-mobility after Comp application.	

Authors	Experimental Design	Fertilisation	Results	Remarks
			Crop-by-product St no final interpretation.	
Vogtmann et al., 1996[SP447]	2 fieltrials, 7 years, plantquality	BWC (60 Mg ha^{-1}) and MC_H (47,5 Mg ha^{-1}) before planting	HM-content of both comp variations sign. lower in comparison to NPK and commercial fertilizer variation. Highest load in control because of low Cd-export through crop-yield. During 7 years no increase in Zn- and Cd-concentrations. Cd-transfer to plant minimal, positive influence through Comp application. Application rates of 10t/d.m. ha^{-1} should not cause any problems.	*soil:* Cd ↓; Zn, Cd no influence after 7 years *plants*: HM-content ↓
Warman et al., 1995[SP448]	greenhouse, loamy sand; yield, plant content, total-metal-uptake Beta vulgaris cv Lucullus	MC with Slu (highly polluted, 15 %), 0, 25, 50 75 and 100 % vol	For Cd, Cr, Hg: the total HM-uptake and the HM-content of the plant tissue increased with increasing Comp applications. This pattern did not apply to Zn, Cu, Ni, Pb, Se-uptake. Higher HM-contents were detected in plant-tissue, despite low application rates. Total metal content correlates with the DTPA-extractable metals in the growth medium.	*plant*: Cd, Cr, Hg ↑ Zn, Cu, Ni, Pb, Se no influence
Weissteiner, 2001[SP449]	Field trial, 1993 – 1999, loamy silt ; CR: Corn-M – Soy – W-W – W-Bar – FP – Corn-M – W-W,	BWC/MC some +/– compoststarterbacteria [MC_B], 12,5 – 24 Mg d.m. ha^{-1} (= 21 – 38,4 Mg f.m.) and year, 7 variations; (with and without min. NPK-supplementation, with and without application of chemical-synthetic fertilizers), standard=customary, conventional, (NPK without Comp)	The HM-input is traceable, but not alarming. The only element which was detected in the soil in higher amounts was Zn. Some of the the Comp had not achieved quality grade I.	Very high Comp application rates! *soil:* Zn ↑ caused by Comp with high Zn-content.

3.8 Pesticides and organic pollutants

3.8.1 Behaviour of organic pollutants during composting and in compost amended soils

With respect to organic pollutants in soils compost application can have various effects. Compost organic matter may due its sorption capacity reduce the mobility of toxic compounds. Further, the compost induced improvement of soil microbial activity contributes to an oxidative decay of pollutants. On the other hand this degradation potential is limited and little is known about the long term behaviour of organically bound organic pollutants (Brändli et al., 2003[SP450]). Büyüksönmez et al. (2000[SP451]) surveyed contents and degradation processes of pesticides in compost and in compost amended soils. The identified compounds, mainly pesticides constituents (organo chlorine compounds) are found in very low concentrations. Insecticides (e.g. organo phosphates, carbamates) and most of the herbicides were hardly be detectable. The substances most resistant against the decomposition were organo chlorine compounds.

The principle mechanisms responsible for the decay are (Büyüksönmez et al., 2000[SP452]):

- partial degradation to secondary compounds (metabolites)
- adsorption
- Humification
- volatilisation
- mineralisation

Pesticide decay during composting takes place similarly as may be observed in soil. Extent and mechanisms are mainly influenced by type pesticide, rotting conditions (moisture, microbial community and efficiency and duration of composting process.

The adsorption of non-ionic and non-polar pesticides and other organic contaminants occurs mostly on the soil organic matter fraction. Since the highest content of soil organic matter occurs in the surface horizons of soils, there is a tendency for most organic contaminants to be concentrated in the topsoil. Migration of organic contaminants down soil profiles occurs to the greatest extend in highly permeable sandy or gravely soils with low organic matter contents. High concentrations of water soluble organic matter can cause enhanced mobility and leaching of organic contaminants in soils due to the binding of the contaminant to the soluble ligand. Similarly the erosion of surface soils by water and wind will lead to movement of organic materials together with bound organic pollutants.

With respect of pesticide contamination, most are relatively insoluble and do not move down the soil profile, but there are exceptions which can be readily leached. The main pollutant pathway of pesticides involves transfers adsorbed to organic particles in solution or suspension.

In some cases where organic wastes, such as sewage sludge and some composts, are added to soils, they may act as both a source and a sink of organic contaminants (as well as of metals).

Adsorption of organic contaminants depends on their surface charge and their aqueous solubility, both of which are affected by pH. For many organic contaminants, adsorption on to soil colloids and the presence of water are important factors promoting decomposition by microorganisms. The range of factors affecting the degradation of organic contaminants by microorganisms includes: soil pH, temperature, supply of oxygen and nutrients, the structure of the contaminant molecules, the water solubility of the contaminant and its adsorption to the soil matrix (and therefore to the organic content of the soil).

The persistence of organic contaminants in the soil is determined by the balance between adsorption on to soil colloids, uptake by plants and transformation or degradation processes.

Here some examples demonstrating the impact of compost on decay and fixation of pesticides and other organic pollutants.

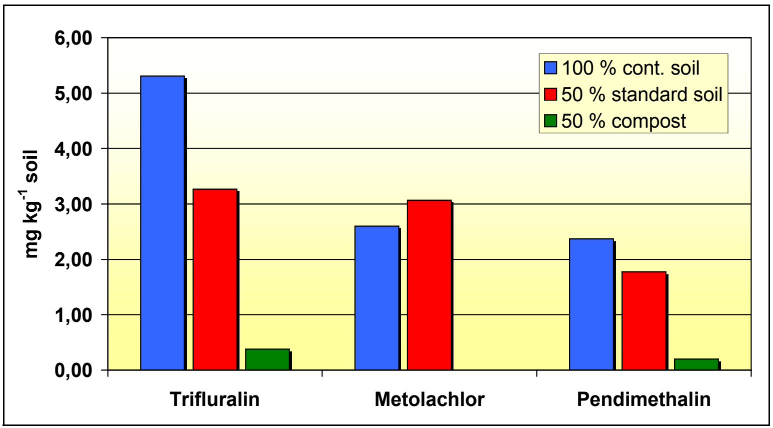


FIGURE 3-35: DECAY OF PESTICIDES IN SOIL-COMPOST BLENDS AFTER 40 DAYS, CROPPED WITH MAIZE (COLE ET AL., 1995[SP453])

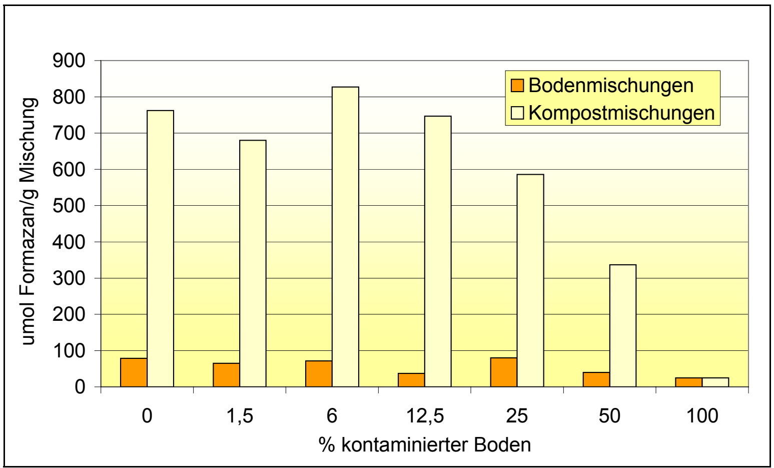


FIGURE 3-36: DE-HYDROGENASE ACTIVITY IN CONTAMINATED SOIL WITH OR WITHOUT COMPOST ADDITIONS (COLE ET AL., 1995[SP454])

In a compost amended soil incubated for 40 days and cropped with maize a nearly complete degradation of three herbicides was observed (Cole et al., 1995[FA455]).. The authors argued this with the increased microbial activity.

Best results were obtained with 50% compost additions.

De-hydrogenase activity at increasing additions of contaminated soils was severely detracted only from 50% soil additions (Figure 3-36). But still then the compost causes a satisfactory degradation of the herbicide.

It is well known that composting processes and compost additions to mineral oil contaminated soils result in effective carbo-hydrate degradation which is widely used in remediation projects for contaminated soils. (Hupe et al., 1996[FA456]).

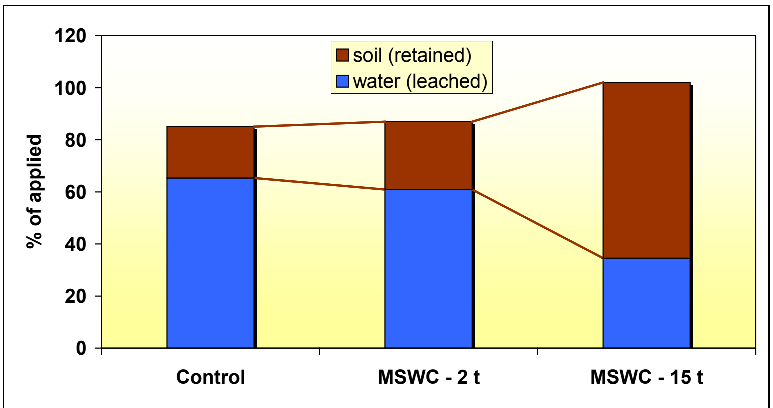


FIGURE 3-37: RETAINMENT AND LEACHING OF DIAZINON IN A COMPOST AMENDED SOIL (SANCHES-CAMANZANO ET AL., 1997)

The improvement of sorption of hydrophobe pesticides is well correlated with maturity and quantity of compost additions (e.g. Diazinon and Linuron: Iglesias-Jimenez et al., 1997[FA457]; Atrazin, Simazin, Terbutryn, Pendimethalin, Dimefuron: Barriuso et al., 1997[FA458]).

This phenomenon is explained with the colloidal structure of humic substances which alters the distribution and availability of hydrophobe and hydrophiliy surfaces of the soil matrix.

Percolatioj trials carried out by Sanches-Camanzano et al. (1997) support the experience of increasing the retainment capacity – in this case for Diazinone – in compost amended soils (Figure 3-37).

Discussing beneficial effects of compost in this respect microbial degradation is the key process, for which optimised conditions would be desirable. This comprise O_2 availability, humidity, temperature, properties of organic matter. Following Büyüksönmez et al. (1999[SP459]) abiotic (photolysis, hydrolysis)and biotic transformation processes take place concurrently, the latter are considered as the most important ones. Metabolites from degradation of primary substances may contain functional groups which might build covalent bonds with functional groups of humic substances. It has been shown that with advanced maturation also the organic binding of pollutants is improved. This is consistent with the phenomenon of aging i.e. the progressive fixation of organic pollutants in soil in time.

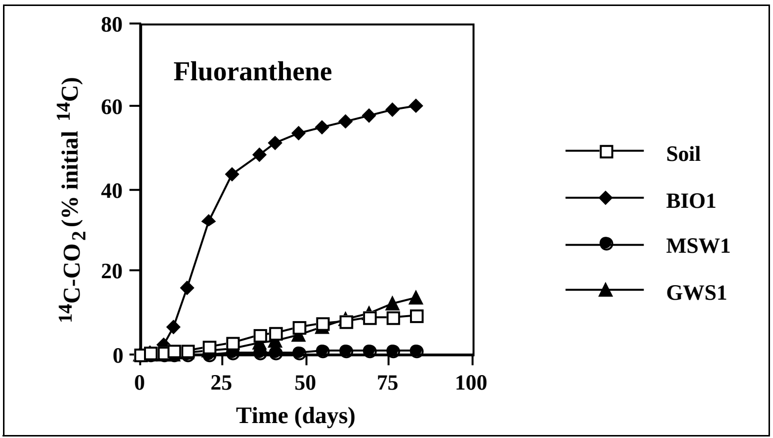


FIGURE 3-38: KINETICS OF FLUORANTHENE MINERALISATION DURING INCUBATION IN SOIL OR COMPOSTS. RESULTS ARE EXPRESSED IN PERCENT OF THE INITIAL RADIOACTIVITY (HOUOT ET AL., 2003)

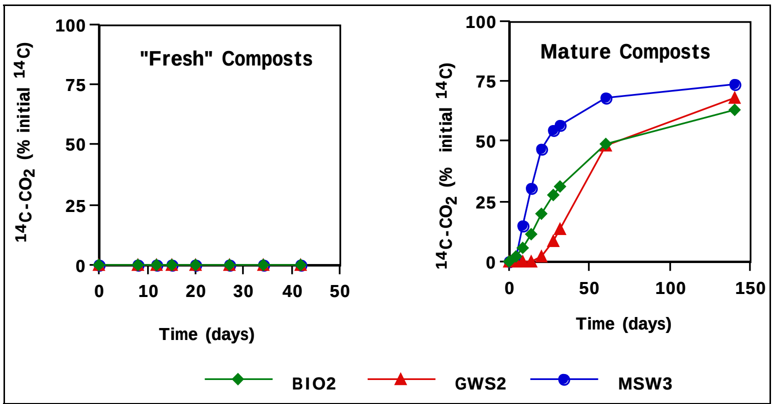


FIGURE 3-39: IMPACT OF COMPOST MATURITY ON THE PRESENCE OF MICROFLORA DEGRADING ORGANIC MICROPOLLUTANTS : ^{14}C-FLUORANTHENE MINERALISATION IN 3 «FRESH» AND «MATURE» COMPOSTS SAMPLED IN THE SAME COMPOSTING PLANTS (HOUOT ET AL., 2003)

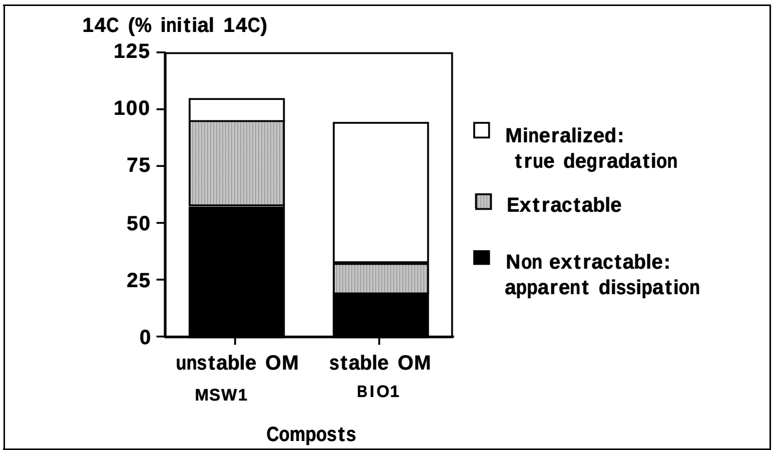


FIGURE 3-40: DISTRIBUTION OF ^{14}C ADDED IN THE MINERALIZED, EXTRACTABLE AND NON EXTRACTABLE FRACTION, AFTER INCUBATION OF ^{14}C-FLUORANTHENE IN SOIL-COMPOST MIXTURES. INFLUENCE OF COMPOST ORGANIC MATTER STABILITY (HOUOT ET AL., 2003)

Houot et al. (2003[FA460]) investigated the decay of *polycyclic aromatic hydro-carbons* (PAH) during composting.

With the exception of one mixed waste compost (MSW1) all composts (biowaste compost - BIO1; green waste-sewage sludge compost - GWS1) led to a good mineralisation performance (60%) of Phenanthrene.

The highest mineralisation rate – also 60 % – of Fluoranthene was achieved in BIO1. As for the other compounds, again in mixed waste compost nearly no degradation was observed (Figure 3-38).

Figure 3-39 shows that the degradation of ^{14}C- marked PAH was detected only in mature compost. It can be concluded that the microbial community present in fresh compost is not able to degrade organic compounds substantially. This was already described by Martens (1982).

Fluoranthene has been degraded at rates between 50 and 70% on all fully matured composts, whereas benzo(a)pyren mineralised only for 30 % in one case.

Also jn compost soil blends, only mature compost additions were effective (BIO1 in Figure 3-40).

If fresh only partly rotted material was used the major part of the transformed fluoranthene was found in the extractable fraction.

This is an clear indication that predominantly microbial species and communities dominating the maturation process are able to mineralise PAH and other carbo-hydrates.

Here follows a short summary on oxidative degradation of exemplary organic pollutants during composting (see Amlinger et al., 2004[FA461]).

The observed reduction of *Polychlorinated biphenyls PCBs* during composting was up to a maximum of 45 % through either bio-degradation or volatilisation. However, there are considerable uncertainties since, given the concurrent mineralisation/volatilisation of part of the organic substrate, generally higher concentrations attended to be found in compost than in feedstock. Degradation occurs mainly for congeners with lower chlorination.

In general *Polychlorinated dibenzodioxins and dibenzofurans (PCDD/F)* tended to concentrate during the degradation process, mostly due to the mass loss during mineralisation of organic matter. Biowaste and green waste feedstock shows generally lower concentrations than the finished composts. The reported initial generation during the rotting process only contributes to a negligible degree to dioxin content in composts and only occurs with temperatures > 70°C and in the presence of primary substances such as trichlorophenol and pentachlorophenol. Here it is important to say that properly managed processes keep temperatures in the range of 45 to 60°C. Higher temperatures are sought only for a short period to ensure sanitisation, although many regulations just mandate 55 to 60 °C to be reached for hygienisation. Most tests conducted during the composting process of biowaste showed an increase of hepta- and octa- PCDD. On the other hand, the content of low chlorinated PCDD/PCDF decreased during the composting process (thereby leading to a decrease in overall toxicity). Furans also generally diminished.

Linear alkylbenzene sulphonates (LAS), Nonylphenols (*NPE*) *and Di (2-ethylhexyl) phthalate (DEHP),*: are all rapidly degraded under aerobic composting conditions.

3.8.2 Assessment of potential accumulation of persistent organic pollutants (PCB, PCDD/F und PAK) by regular compost application

Amlinger et al., 2004 have computed accumulation scenarios for three of the most investigated persistent organic pollutant groups: PCB, PCDD/F und PAK.

Based on investigated background concentrations in composts, in soils and realistic ranges for half-life times [$t_{1/2}$] these are the assumptions used for the scenarios

TABLE 3-35: ASSUMPTION FOR PCB, PAH AND PCDD USED IN ACCUMULATION SCENARIOS (AMLINGER ET AL., 2004)

		PCB		PAH		PCDD/F	
Half-life in soil							
	(1)	12	years	16	years	30	years
Atmospheric deposition							
	(2)	2	g ha^{-1} y^{-1}	8	g ha^{-1} y^{-1}	29	µg ha^{-1} y^{-1}
Export							
Export (leaching and harvest)		Not assessed; no consistent data available					
Background value soil as starting point for the accumulation in the soil							
LOW	(3)	0.01	mg Kg^{-1}d.m.	0.05	mg Kg^{-1}d.m.	2.44	ng TE Kg^{-1}d.m.
HIGH	(4)	0.04	mg Kg^{-1}d.m.	1	mg Kg^{-1}d.m.	13.30	ng TE Kg^{-1}d.m.
Soil threshold values for multifunctional use							
LOW		0.05*	mg Kg^{-1}d.m.	3*	mg Kg^{-1}d.m.	5**	ng TE Kg^{-1}d.m.
HIGH		0.1*	mg Kg^{-1}d.m.	10*	mg Kg^{-1}d.m.	40**	ng TE Kg^{-1}d.m.
Concentration in compost							
Minimum of means	(5)	0.01	mg Kg^{-1}d.m.	0.6	mg Kg^{-1}d.m.	4	ng TE Kg^{-1}d.m.
Maximum of means	(5)	0.10	mg Kg^{-1}d.m.	4.6	mg Kg^{-1}d.m.	12	ng TE Kg^{-1}d.m.
Assumed high	(5)	0.25	mg Kg^{-1}d.m.	13	mg Kg^{-1}d.m.	18	ng TE Kg^{-1}d.m.
Quantity of compost per ha and year applied							
max. **60 Kg P_2O_5 ha^{-1} y^{-1}** (P_2O_5 compost: 0.65 % d.m.)						→ **9.2 t d.m. compost ha^{-1} y^{-1}**	
Soil depths and density						30 cm / soil density: 1,5 g cm^{-3} ; → **4,500 t ha^{-1}**	
Time frame for the accumulation model						**100 years**	

(1) PCB: di Domenico & De Felip[SP462] (2000); PAH: Knudsen et al. (2001[SP463]) and PCDD/F: Shatalov et al. (2002[SP464])

(2) max. annual load per ha taken from Kupper & Becker van Slooten (2001 [SP465])

(3) median of background values on arable land or rural soils (PAH) (Erhardt & Prüeß, 2001.

(4) 90%ile of background values on arable land or rural soils (PAH) (Erhardt & Prüeß, 2001**[SP466]**).

(5) Background concentrations in compost taken from Amlinger (2004)

* Precautionary soil threshold values of organic pollutants for soils (German Soil Protection Ordinance, BBodSchV, 1999[FA467]); low and high values for soils with an organic matter content < and > 8 % respectively.

** Guide values for the use and remediation of soils for agricultural and horticultural use (working group on Dioxins Germany, 1992); 5 ng TE Kg^{-1}dm = target value; any soil use is possible; 40 ng TE Kg^{-1}dm = threshold for control measure and recommendation for precautionary action.

The accumulation was computed by using the following iterative formula:

$$C_n = C_0 \times x^n + \frac{I_F + I_D - E_L - E_H}{M_S + M_S} \times \frac{1 - x^n}{1 - x}$$

where is:

$$x = e^{\frac{-\ln(2)}{t_{1/2}}}$$

C_n … *compound concentration in year n [mg or ngI-Teq Kg^{-1} d.m.]*

C_0 … *compound concentration in year 0 [mg or ngI-Teq Kg^{-1} d.m.]*

n … *years for which accumulation is considered*

I_F … *input of compound by fertiliser application [g or µg ha^{-1}y^{-1}]*

$I_F = C_F. \times M_f$

= C_F… compound concentration in fertilizer applied [mg or ngI-Teq Kg^{-1} d.m.]

I_D … *input of compound by atmospheric deposition [g or µg ha^{-1}y^{-1}]*

E_D … *export of compound by leaching [g or µg ha^{-1}y^{-1}]*

E_H … *export of compound by harvest [g or µg ha^{-1}y^{-1}]*

M_s … *Mass of soil layer concerned [t ha^{-1}]*

M_f … *Mass of compost addition that remains in the soil after mineralisation [t ha^{-1}y^{-1}]*

$t_{1/2}$… *half-life time of compound in the soil*

Figure 3-41, Figure 3-42 and Figure 3-43 show the soil change for PCB, PCDD/F and PAH respectively based on the assumptions given in Table 3-35.

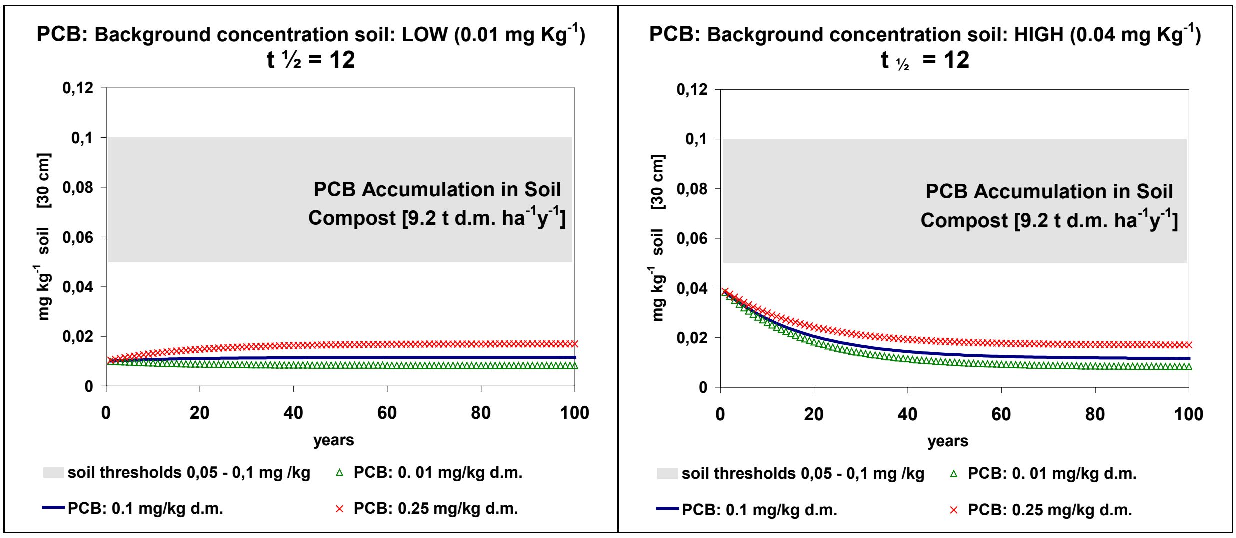


FIGURE 3-41: CHANGE OF CONCENTRATIONS OF *PCB* DUE TO CONTINUOUS YEARLY COMPOST APPLICATION. *GREY AREA … RANGE OF THRESHOLD VALUES FOR SOILS ; $T_{1/2}$ = HALF LIFE TIME (AMLINGER ET AL., 2004)*

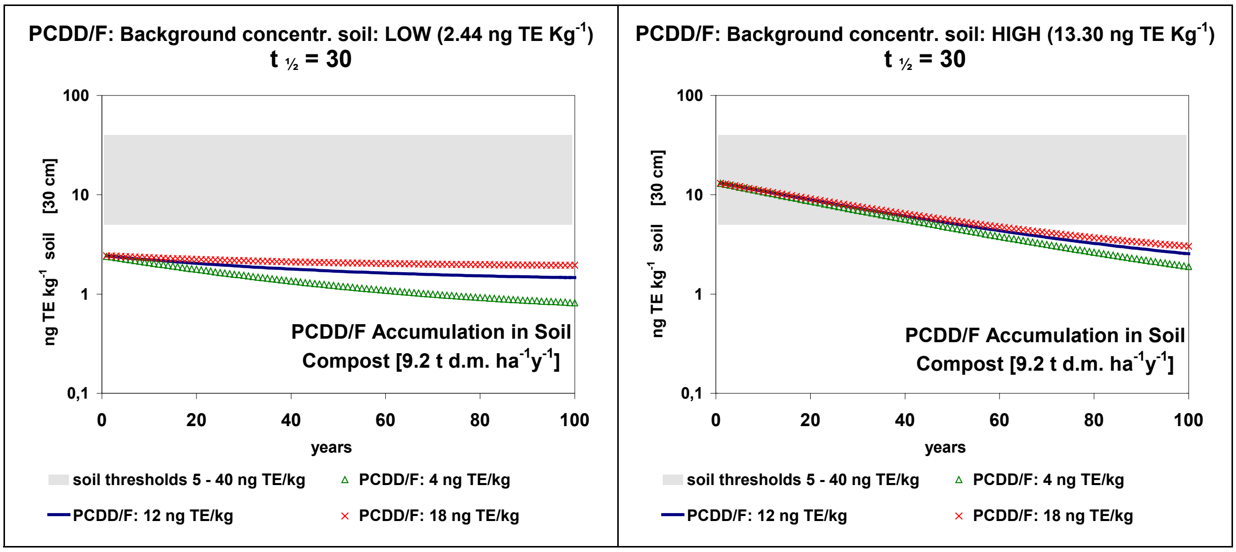


FIGURE 3-42: CHANGE OF CONCENTRATIONS OF <u>PCDD/F</u> DUE TO CONTINUOUS YEARLY COMPOST APPLICATION. *UNDERLAID GREY AREA … RANGE OF THRESHOLD VALUES FOR SOILS ; $T_{1/2}$ = HALF LIFE TIME (AMLINGER ET AL., 2004)*

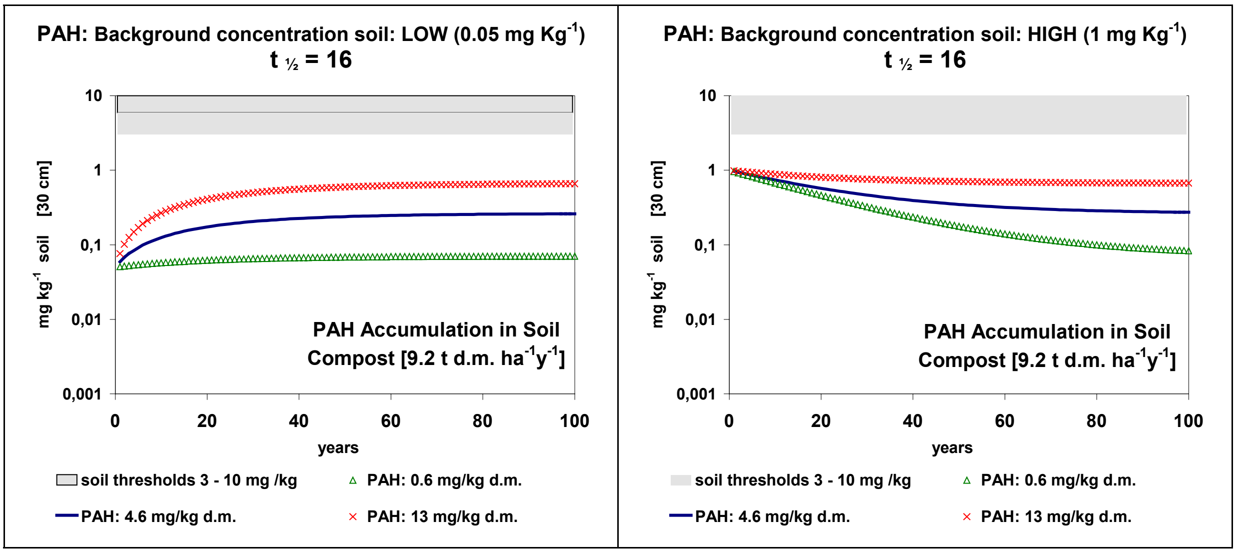


FIGURE 3-43: CHANGE OF CONCENTRATIONS OF <u>PAH</u> DUE TO CONTINUOUS YEARLY COMPOST APPLICATION. *UNDERLAID GREY AREA … RANGE OF THRESHOLD VALUES FOR SOILS ; $T_{1/2}$ = HALF LIFE TIME (AMLINGER ET AL., 2004)*

From the computation of accumulation in a certain soil layer it is evident that the graph is not linear and it would approach an asymptotic curve in relation to the concentration level in compost, taking into account the site and management specific long-term mineralisation rate of the compost and the half-life of the contaminant in soil.

For each compound two scenarios with a standard half-life time are shown, one with a lower and one with a higher starting point (background concentration) in soil.

The results show that under consideration of the assumed half life times, with the exception of PAH at a very low background concentration, regular compost application plus atmospheric deposition would not lead to a considerable accumulation in the soil. The natural degradation would over-compensate the input. Important is here again that the potential soil change with reference to the background of scientifically approved critical threshold values for the multifunctional or agricultural use of soils. This should include also precautionary aspects of general soil functions and water protection (see also Aldrich & Daniel, 2003[SP468])

Again the principle, as already demanded for the heavy metals, must be to use clean and well defined source materials which in itself guarantee the highest possible quality or. In other words the lowest possible contamination with organic pollutants. This again is the pre-requisite to keep any potential input or accumulation of pollutants on soils as low as technical feasible.

From the data viewed it can be concluded that compost from source separated organic input materials would, even in regular application scenarios not contribute to a measurable increase of organic pollutants, rather they would implicate a better fixation and, on the other hand, enhanced degradation of organic compounds.

3.8.3 Experimental results on the behaviour of pesticides und organic pollutants in composting and compost amended soils – tabular survey

TABLE 3-36: EXPERIMENTAL RESULTS ON THE BEHAVIOUR OF PESTICIDES UND ORGANIC POLLUTANTS IN COMPOSTING AND COMPOST AMENDED SOILS – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Barriuso et al., 1997[SP469]	Longterm-laboratory-incubation-experiment, investigates the transformation of 8 herbicides after Comp application. soil: soil, Comp and soil-Comp-blend soil: (typic Eutrochrept) pH 7,3, 22% clay, 73 % sludge (silt), 1,08 % org. C and 0,13 % org. N in d.m. (herbicide solutions), periodical water content control and (14C)CO2-measurements. At the end of the incubation time: extraction with methanol, extracted radioactivity measured directly, non extractable radioactivity corresponds with the bound residue.	MWC, age: 8,5 months, pH 8,5, 16,87 % org. C, 1,34 % org.N in d.m.. Comp fraction: 10, 20 u. 30 % (m/m) 8 herbezides: pendimethalin, simazin, dimefuron, terbutryn, atrazine, 2,4 D, metsulfuron-methyl and carbetamide were added to soil-Comp-blends (10, 20 and 30% Comp) resp. pure Comp (1:1 blend with sand), incubationtime: 8 months, 28 °C, darkness; 95 % waterretention capacity (incl.)	The Comp addition prevents the mineralization of the herbicide and supports the stabilization of herbicide residue. Part of the stabilized residue remained extractable and potentially available, but the main fraction remained unextractable and the residuals were bonded. The sorption might be the beginning of a kinetically limited biodegradation, especially with strongly bonded herbicides (atrazine, simazine, terbutryn, pendimethaline, dimefurone). The Comp application has little influence on the less bonded herbzides (carbetamide, 2,4D and metsulfuron-methyl).	sorption, mineralization, herbizides
Brown et al. 1997[SP470]	9 composters, metalbarrels, 200 l, perforated, 4 volatile organic chemicals added (VOCs): benzene, Carbotetrachloride, dichlorbenzene and xylene, which are also found in housholdproducts. The volatilization was measured (activated carbon filter and GC) as well as the leachate (GC), and the condensate under the Comp.	MWC	The majority of the VOCs was lost within 48 hours of composting via volatilization. Leachate content and VOCs were below detection limit within one week. The initial concentrations of 275 mg/Kg captan and lindane were reduced to 53,8 resp. 158,9 mg/Kg, within 5 weeks of Comp process. All concentrations in air, condensate and leachate were below detection limits for both pesticides, meaning neither one was volatilized, but complexed or degraded within the Comp material.	
Cole et al., 1994[SP471]	Pesticide contaminated (22 pesticides) soil blended with uncontaminted soil and Comp;	Garden-waste Comp, blended with soil: 0; 1,5; 6; 12,5; 50 % w/w	Fungal- and bacterial populations of 100.000 up to several billionen units/g root; sign. increase of crop yield and bacterial populations in Comp containing	

Authors	Experimental Design	Fertilisation	Results	Remarks
	M, 15 cm pots, greenhouse; bacteria- and fungal cultures from soil and rhizoshere after collection in buffersolution on agar; dehydrogenaseactivity		blends, in comparison to contaminated soils, populations in soil-blends not affected. Fungal populations in Comp variations with and without plants sign. higher than in contaminated soils, dehydrogenase-activity ***sign***. higher in Comp blends than in soil blends.	
Cole et al., 1995[SP472]	Pesticide contaminated soil; pH 8,3 investigation of herbecide inactivation analysis of substrate blends regarding herbecides after 40 days of maize crop	Contaminated soil was blended with uncontaminated soil resp. with GWC (0; 1,5; 6; 12,5; 25; 50; 100 %).	The combination of plants and Comp resulted in sign. higher herbecide-inactivation in contaminated soils. 50:50 blends of contaminated soils: Comp most favourable. Many of the Comp containing blends effected an increased pesticide inactivation/degradation (higher microbial activity).	pesticide decomposition ↑
Franco et al., 1996[SP473]	Alpechìn (lquid phytotoxic wasteproduct of olivoil extraction) absorbed into Comp and incubated (12 days, 50 days), silty loam	Cottonwaste Comp, blends: 80:15 (v:v) Alpechìn-soil with and without Comp 15:5 (v:v)	Toxicity neutralized through Comp addition; plantgrowth enhanced, negative influence of alpechìn on the microbial biomass of the soil without Comp.	
Houot et al., 2003[SP474]	Laboratory analysis PAH (Flouranthen)-addition and incubation in soil, Comp and soil- Comp blend	MWC, BWC, BW/Slu-Comp	Mature Comp application → stable OM → less total mineralization, but high mineralization of PAH during incubation of immature (fresh) Comp immature (fresh) Comp → high total mineralization → less degradation of PAH and increased formation of non extractable residues	Importance of Comp maturation regarding the degradation of organic toxins!
Hupe et al., 1996[SP475]	Dieseloil contaminated (1% w/w TM) modelsoil, enclosed bioreactor, CO_2- and VOC-measurement	BWC, soil: Comp 2:1, 4:1 and 8:1 (d.m.)	Sign. support of degradation with blend of soil:Comp 2:1, no influence of Comp maturity	
Iglesias-Jimenez et al., 1997[SP476]	Laboratory, incubation 2 and 8 months, sandy loam, pH 7,5, two slightly watersoluble pesticides (diazinon and linuron)	BWC, peat, humic acids, a.o.	In all cases r^2 of 0,99 and higher were found for the Freundlich isotherm. The values for the sorption constant K in natural soils were at 8,81 for diazinon und 2,29 für linuron. These values increased sign. in modified soils, meaning the sorption capacity regarding hydrophobic pesticides increases with the degree of maturation, of the materials added to soils (humic-type compounds), possibly due to the colloidal characteristics of the material and the changes induced	sorption capacity increased through Comp application

Authors	Experimental Design	Fertilisation	Results	Remarks
			regarding the hydrophobic-hydrophilic characteristics of the soil surfaces.	
Liu & Cole, 1996[SP477]	Greenhouse, M, 4 weeks, pesticide contaminated soil, dehydrogenaseactivity, yield	GWC 0, 1, 5, 10, 20, 40 % Comp	Decomposition of pesticides through 20 resp. 40 % Comp, after 4 weeks incubation and 16 weeks in the laboratory: 85 % (trifluralin), 100 % (metolachlor) and 79 % (pendimethalin).	
Michel et al., 1996[SP478]	Laboratory experiment: investigation of the behaviour of 3 lawncare-pesticides (2,4-D; diazinon, pendimethalin) in Comp., volatilization, mineralization, washout, localization.	Laboratory Comp, greenwaste with grass, leaves, C14 marked pesticides added	The pesticide reaction varies: the majority of 2,4 D was mineralized, the majority of diazinon was transformed to watersoluble products of low toxicity, the majority of pedimethalin was complexed in non extractable substances.	Pesticide reaction during Comp process!
Sanchez-Camazano et al., 1997[SP479]	greenhouse, soil columns, cambic arenosol, C14-marked diazinon	BWC, 2t and 15 Mg ha^{-1}	Clear retention with BWC (higher application > lower application), cumulative fraction of the applied diazinon was at ca. 60 resp. 34 % in contrast to ca. 65% on control. The main influence regarding the retation of the hydrophobic pesticide diazinon in Comp may be the compounding with the org. Subst. (but also the mineral fraction), especially the humin and fulvic acids with hydrophobic bridges, but also the interaction with OH and COOH groups of the humic- and fulvic acids or with the clay minerals of the soil.	
Timmermann et al., 2003[SP480]	Long-term compost experiment (8 resp. 5 years): duofactorial split-plot facility with 12 variations at 4 replications. random. → 48 plots per experiment 6 sites : lS, uL, uL, utL, uL, sL CR: M – W-W – W-Bar	Comp application: 0; 5; 10; 20 Mg ha^{-1} N-suppliments: N0: no N; N1: 50 % of the optimal N-level; N2: 100 % of the optimum N-level on basis of the Nmin-content of the soil as well as further aspects, like prceeding crop etc. (nitrate information service - NIS).	Even excessive comp applications (level K3) did not increase the soil content of PCB and PCDD/F, which were mostly on a very low ubiquitious level below the limits. The total content in the Comp was generally at a very low level and was in the case of PCDD/F slightly retrograde, and therefore no problem regarding the agricultural use of Comp. The toxin-freights were very low, even with excessive Comp applications (level K3), accordingly there was no detectable increase to be expected.	

3.9 Soil biology

3.9.1 Introduction

An enormous number and variety of organisms are living in the soil. They have a central task in maintaining “healthy” soils with all its ecological functions so to say soil fertility.

Soil organisms are all organisms permanently or temporarily living on or in soils. Soil organisms can be allocated to three different trophic levels on account of their ranking in the nutrient circle (Scheffer & Schachtschabel et al., 1998[SP481]): saprophagous, phytophagous und mycophagous primary destruents feed on dead or living organic matter (e.g. protozoa, actinomycetes, some nematodes, earthworms)

- Koprophagous secondary decomposer utilise the digestion products of the primary destruents (e.g. nematodes, enchytraeidae)
- Zoophagous predator are living on other soil animals and contribute to the regulation of prey population (e.g. spiders, moles)

The classification of soil organisms is mostly carried out on behalf of their body size:

- Microorgansims: bacteria, actinomycetes, fungi, algae and protozoans
- Microfauna (< 0,2 mm): e.g. flagellates, paramecium, rhizopodae
- Mesofauna (0,2 – 2 mm): e.g. rotifers, nematodes, mites, collembola
- Macrofauna (2-20 mm): e.g. spiders, beetles (larva), woodlouse
- Megafauna (>20 mm): e.g. earthworms, moles, spiders

TABLE 3-37: NUMBERS OF ORGANISMS AND APPROXIMATE MASS PER M² OF A FERTILE AND WELL DRAINED SOIL (SEVERAL SOURCES)

	Organism	Numbers /m^{-2}	Mass /m^{-2} (g)	Mass ha^{-1} (Kg)
Microorganisms	Bacteria	10^6 x 10^6	50	500
	Actinomycetes	10^4 x 10^6	50	500
	Fungi	10^3 x 10^6	100	1.000
	Algae	1 x 10^6	1	10
	Protozoa	1 x 10^6	<1	
Soil fauna	Earthworms	70	40	400
	Enchytraeid worms	1 x 10^4	2	20
	Gastropods	65	1	10
	Millipedes	75	2.5	25
	Centipedes	65	0.5	5
	Mites	1 x 10^5	1.0	10
	Springtails	5 x 10^4	0.6	6
Summe			**ca. 250 g**	**ca. 2.500 Kg**

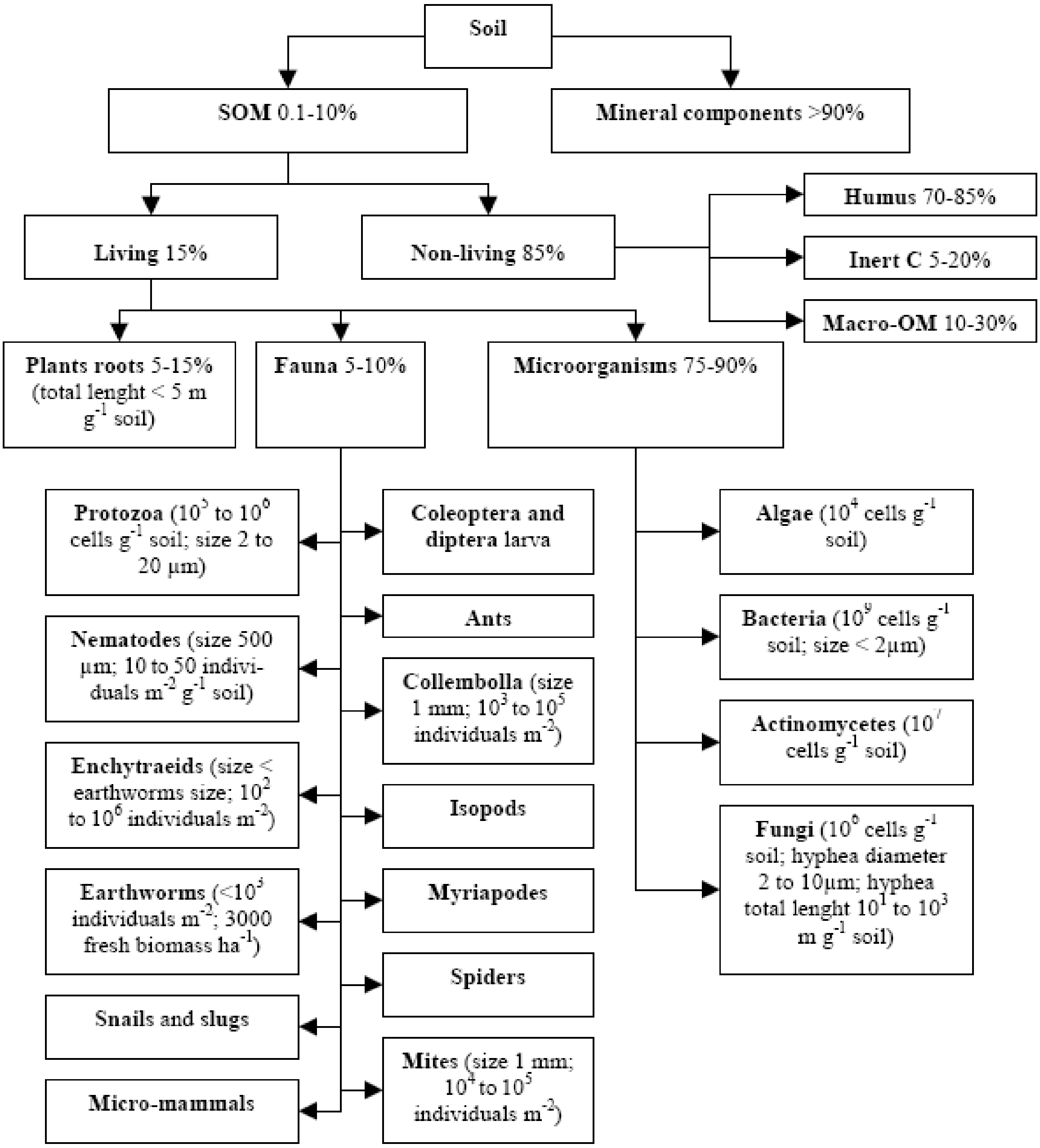


FIGURE 3-44: COMPOSITION OF SOIL BIOTA OF A TYPICAL FERTILE SOIL (FROM VAN-CAMP ET AL., 2004)

It has been calculated that there might be of the order of 2.4 tonnes of soil organism per hectare in a fertile, well aerated soil. This is equivalent to 5 lifestock units or at least the twofold weight of lifestock that can be kept on 1 ha land.

3.9.2 The function of soil organisms

In natural systems most of the organisms depend upon the addition of the carbon compounds in plant materials (roots, stems and leaves) and the faeces of surface and soil dwelling animals. Indeed one of the key roles of the soil organisms is the incorporation of these materials in to the soil system and their alteration, making major contributions to the cycling of carbon, nitrogen and sulphur and facilitating the release of nutrients contained in the organic material in forms where they can be taken up by plants. The manifold interdependencies of soil biota, site and and management conditions are outlined in Figure 3-45.

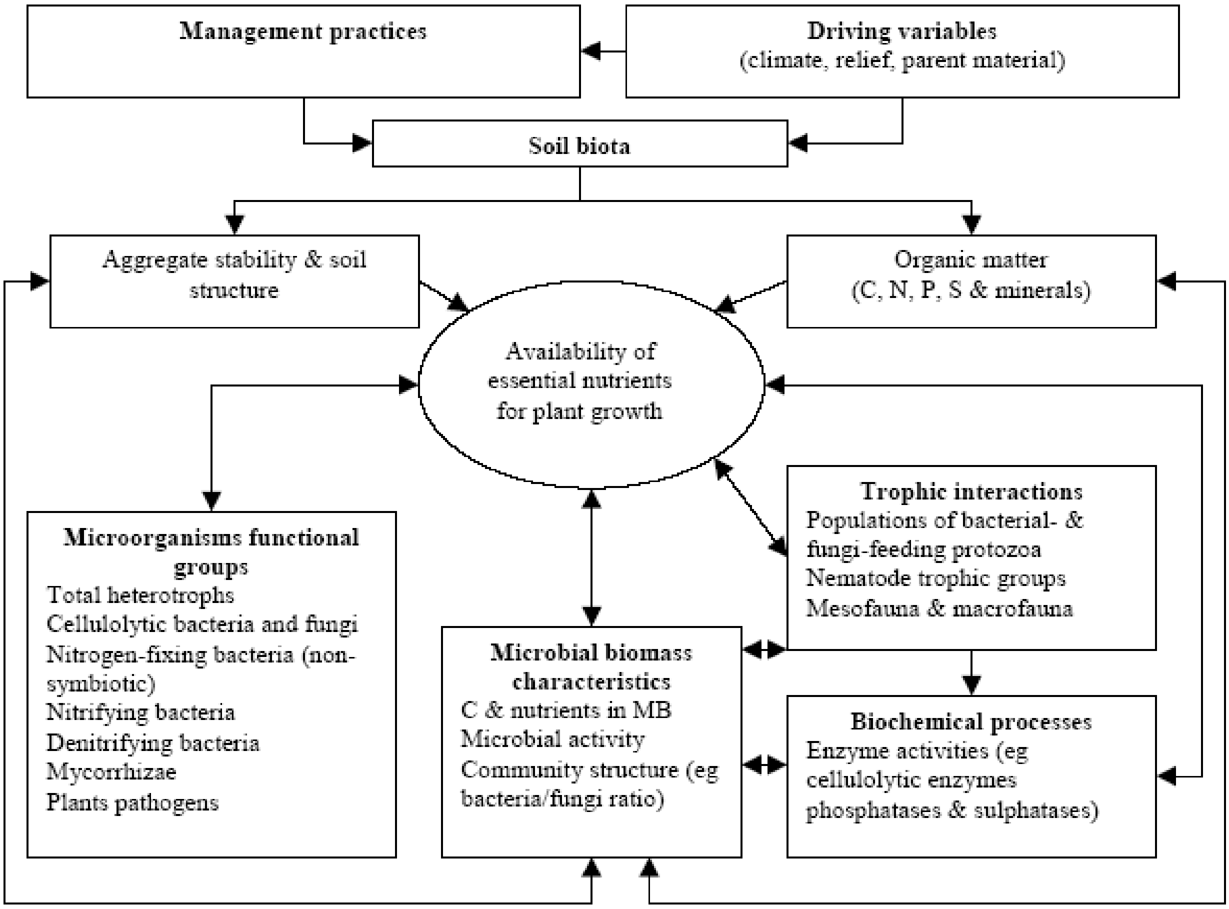


FIGURE 3-45: CONCEPUAL MODEL SHOWING THE VARIOUS FACTORS MEDIATED BY SOIL BIOTA THAT AFFECT THE SUPPLY OF ESSENTIAL NUTRIENTS TO PLANTS (FROM VAN-CAMP ET AL., 2004)

In addition the CO_2 that is respired during these processes, when dissolved in water, forming a weak carbonic acid will assist the weathering of minerals and the release of nutrients. Through the carbon cycle the organisms will assist in maintaining the organic matter pool within the soil, the presence of this organic matter being characteristic of a good and healthy soil.

From the foregoing it is clear therefore that soil organisms play a key role in the normal functioning of the soil systems, but this functioning is dependent upon a supply of available carbon. Where insufficient carbon is added to the soil naturally through plant residues and organisms there must be supplementation through the addition of manures and composts.

Microbial populations are often very sensitive to changes in soil conditions, and where there is a need to regenerate or reactivate the soil system a key action is to endeavour to encourage the activity of the soil microorganisms. For example Table 3-38 illustrates the response of soil bacteria and fungi to a range of conditions from some studies undertaken by the United States Environmental Protection Agency (EPA, 1998). An important point to note in this table is markedly increased activity observed in sites recently reclaimed following surface mining. If this level of activity can be initiated and maintained following reclamation the possibility of soil improvement is much increased. Increasing soil microbial activity must be a key feature of any soil restoration or soil reclamation scheme. The values for the Green waste Compost show the possible benefits of using material of this nature.

TABLE 3-38: POPULATIONS OF BACTERIA AND FUNGI IN SOILS AND COMPOST (EPA, 1998)

Material	Bacteria 10^6 g^{-1} d.m.	Fungi 10^3 g^{-1} d.m.
Fertile Soil	6-46	9-46
Soil recently reclaimed after surface mining	$19^{-1}70$	8-97
Pesticide contaminated mix of silt and clay	19	6
Mature Green waste Compost	417	155

3.9.3 Methods for quantifying biological and microbial activity of soils

The quantitative description of selective or integrative activity parameter for soil specific metabolism processes are consulted today in many respects as indicator for soil quality, soil function, soil productivity, soil health etc. Of these indices the most widely used is microbial biomass. Recently new techniques have been developed which measure enzyme activity, using surrogates such as hydrogenase or protease as representative of the activity of the system.

Microbial biomass is defined as the living component of soil organic matter (Jenkinson and Ladd, 1981), but excludes soil meso and macro fauna and plant roots. There are a number of methods of determination, for example fumigation – incubation, fumigation – extraction and substrate induced respiration methods (Sparling and Ross, 1993).

The following parameters are most frequently found in literature:

TABLE 3-39: SURVEY OF THE METHODS GIVEN IN LITERATURE FOR CHARACTERISATION OF BIOLOGICAL ACTIVITY OF SOILS

Parameter	**Physiological importance for material transformation in soils**
Basal respiration; CO_2-respiration	Indicator for the carbon cycle; sum paramter for the entirety of biological (metabolic-) activities of a soil via measuring the CO_2 release under standardised conditions;
Substrate induced respiration (SIR);	Indirect determination of the microbial biomass or the microbial biomass C (MBC);
Metabolic quotient qCO_2	Is determined from the basal respiratory rate and potential microbial biomass and indicates which amount of CO_2 per hour and per mg of the microbial fixed C is released. This parameter is an indicator on the metabololic capacity related to the potential microbial biomass
Phosphatase-activity	Enzyme of the phosphorus cycle which mineralises organically bound phopsphate (e.g. phosphoric ester, phytane acid and phytine) to ortho-phosephate that can be taken up by plants. One distinguishes between the acid and alkaline phosphatases. In soil mostly microbially released phosphatase is contained;
Microorganisms	Qualitative and quantitative determination of microbial communitie
heterotrophic N-fixation	Not-symbiotic nitrogen bonds by blue-green algae, Acotobacter, Chlostridium
N-Mineralisation	Determination of N-mineralisation in aerobic and anaerobic breeding tests. Also used for the determination of short-termed N-mobilisation
Ammonium oxidation rate	The nitrification, i.e. the oxidation of ammonium to nitrite and further to nitrate is a process of the N-cycle in the soil with agronomic importance. Populations of nitrificants and nitrification rates are often determined as indicators for a general microbial activity of the soil
Denitrification	Denitrification is the ability of microorganisms, to reduce nitrate selectively to molecular nitrogen by enzymatic activities
Total-Phospholipidphosphate	Extraction method of phospholipide as an essential component of cellular membrane
FDA-HR (hydrolysis of fluorescein diacetate)	
Dehydrogenase-Activity	Enzyme of the intracellular metabolism and for biological redox systems: this parameter is looked upon as integrative indication for the intensity of microbial substance transformations in the soil. Oxidation of organic compounds by separation of 2 hydrogen atoms, several dehydrogenases are effective in the enzyme system of the respiratory metabolism,
Urease	Indicator for nitrogen cycle, in the soil preferably of microbial origin; catalyzes the hydrolysis of urea from animal excrements and nucleic acid to CO_2 and NH_3
Protease	Indicator for the nitrogen cycle. Proteases are excreted by fungi and bacteriae, degradation of proteins to amino acids; posses high stability through binding to carbo hydrates and proteolytical enzymes, sensible towards desiccation
Further methods	β-Glucosidase; AI_{max} (respiration intensity); DMSO (Dimethylsulphoxi reduction)

3.9.4 General interaction: organic matter – organic fertilisation – micro-biology

One of the most important soil functions, the transformation of organic matter, is controlled by soil organisms. The degradation of organic carbon compounds (cellulose, hemicellulose, polysaccharide, hydrocarbon, lingnine and others) makes energy available for heterotrophic organisms which on the other hand are responsible for other metabolic transformations (e.g. asymbiotic N-fixation, protein and aminoa cid degradation, mineralisation and immobilisation of nitrogen, transformation of mineral substances (Roper und Ophel-Keller, 1997[FA482]).

SOM is a direct product of the common biological activity of plants, microorganisms and animals and innumerable abiotic factors (see flowchart in Figure 3-46).

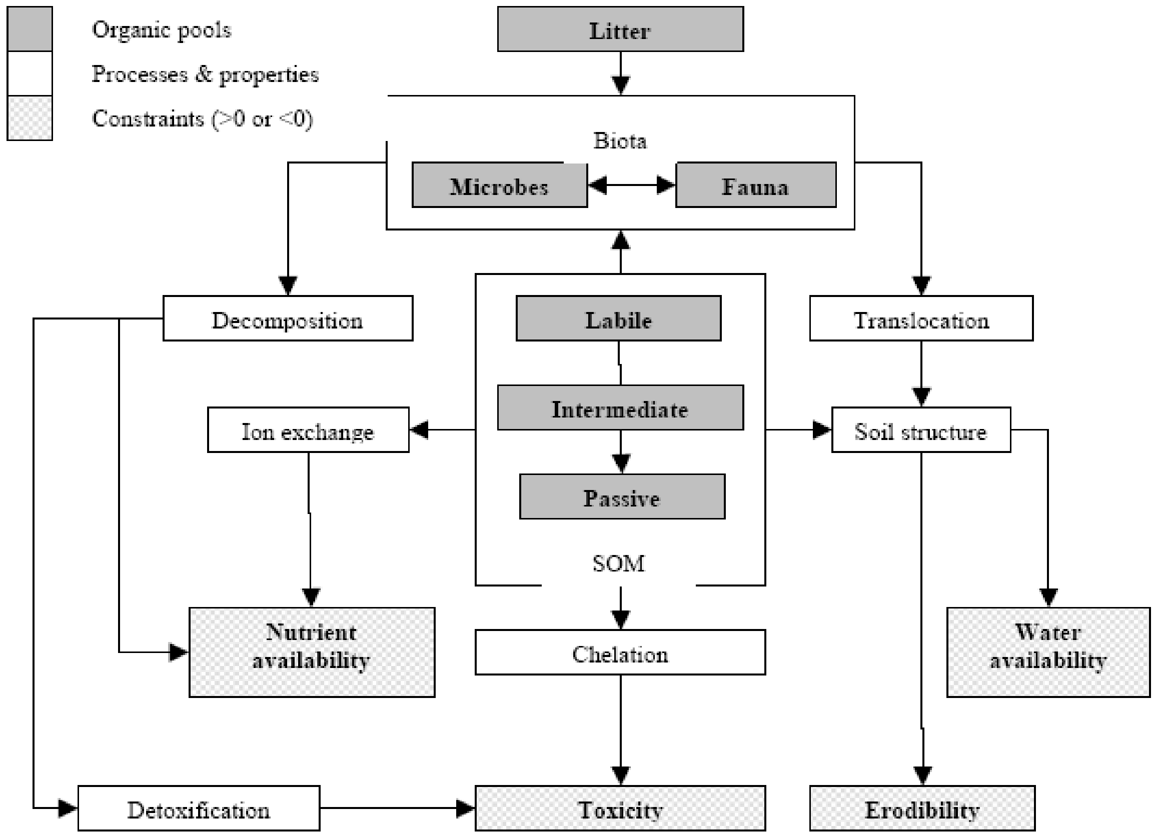


FIGURE 3-46: INTERELATIONSHIP BETWEEN SOIL ORGANIC MATTER AND BIOTA (ELLIOT, 1997[FA483])

As already mentioned the activity of microorganisms respectively the microbial biomass besides other factors (soil temperature, water content etc.) depends above all on the availability of easily degradable nutrient sources. Therefore the application of organic material in form of organic fertilisers or crop residues leads to an increase of microbial activity and biomass.

The organic fertilisation in general and incorporation of compost especially plays a great role for the development of microbial activity (the act of metabolism) of a soil in a threefold sense:

- Optimisation of the habitat (water and air household, enlargement of the specific surfaces for the formation of retained water films as habitat for bacteria colonies and others)

- Incorporation of food substrate, that supports bacterial growth and the following enzymatic activity
- Direct incorporation of microbial populations in the soil.

In evaluating different test procedures to collect functional groups of microorganisms Postma & Kok (2003) proved that different populations of microorganisms with different additives to the soil (e.g. 1% m/m spent mushroom compost, green compost, cellulose) show clearly characteristic patterns in their ability to use carbon sources (BIOLOG method). The genetic profile of the bacteria population was also distinctly differentiated considering the concerning composts and additives. The interesting point is the fact that differences within the functional groups of microorganism populations can be recognised already at low application rates of compost.

3.9.5 Brief excursus – micro-biology of composting

The composting process is an exothermic metabolism process of a successive population of microorganisms, which are transforming the offered substrate at a sufficient oxygen partial pressure to metabolic products. The potential of microbial (rest)-activity of the final product is essentially dependent on the initial materials (substrate, available C- and N-sources), the process conditions (duration, temperature profile, humidity, homogeneity of degradation and transformation, oxygen solubility) and the final degree of stabilisation (synonymous for mineralisation, humification) (de Bertoldi, 1995[SP484]; Grabbe & Schuchardt, 1993[SP485]). For an agricultural or horticultural use microbiological parameters are usually not described as quality criteria (Szmidt, 2000[SP486]). Bess (1999[SP487]) describes a population density of 10^8 g^{-1} d.m. for bacteria and 10^4 g^{-1} d.m. for fungi respectively yeasts as minimum stock for qualitative high-qualified compost. A minimum value of 10^3 g^{-1} d.m. of *Pseudomonadae* is recommended, as for some representatives of this microbial strain exists a positive interaction with plant growth (e.g. *Rhizobium* and *Azotobacter* as symbiotic or free living N-absorber).

A specific utilisation effect connected with the microbial composition of compost is the ability to suppress plant diseases. This socalled *antiphytopathogenic potential* of composts is treated in chapter 3.10.

3.9.6 Impact of compost use on (micro) biological activity of soils – examples from literature

Researches about the effect of compost on the soil biota and the microbial activity of soils respectively were gathered in many cases in research programmes on compost application since the middle of the 90ies.

Bode (1998[SP488]) proved that the microbial biomass and the enzyme activity (β-Glucosidase) are positively influenced by organic fertilisation. The mineral fertilisation did also encourage the microbial parameters, as mineral fertilisation resulted in higher yields and higher crop residues. A positive relation between C_{mic} (microbial carbon) and the amount of crop residues could be shown. An increase of microbial mass, activity and enzymatic reactions could be proved also by Schwaiger & Wieshofer (1996[SP489]) (substrate induced respiration, Protease-, urease- and β-Glucosidase activity) and Poletschny (1995[SP490]) (microbial biomass, Dehydrogenase- and catalase activity) after compost fertilisation for several years respectively after a unique high compost application.

The microbial biomass is subject to considerable fluctuations. It can rise immediately after compost application by the factor 4-6, but decreases rapidly – after the easily degradable organic matter is consumed – and within one year the initial level is reached again (Kögel-Knabner et al., 1996[SP491]).

Two forms of organic matter are decisive for the amount of the microbial biomass and their activity. It can be increased intensely in a short notice by application of organic matter with a high portion of easily degradable fractions. This effect lasts only temporarily. A longer-termed increase of microbial biomass and their activity is only possible if by (long-termed) organic fertilisation the content of organic matter in the soil is increased, as this contributes as a steady nutrient source for microorganisms.

The relation between organic matter and earthworm population is researched to a great extent. It seems that earthworms react in their abundance (population density) preferably on the supply of organic matter than on the organic substance available in the soil. Bode (1998[SP492]) found only a weak positive relation between C_{org}-content of the soil and earthworm population. The assessment of soil areas researched over a longer period of several federal states Hund-Rinke & Scheid (2001[SP493]) found no relation between C_{org}-content and earthworm population. Kämmerer & Süss (1996[SP494]) proved at their researches slightly higher population densities in grassland contrary to arable areas, attributed this, however, to the different cultivation and the influence of soil conditions.

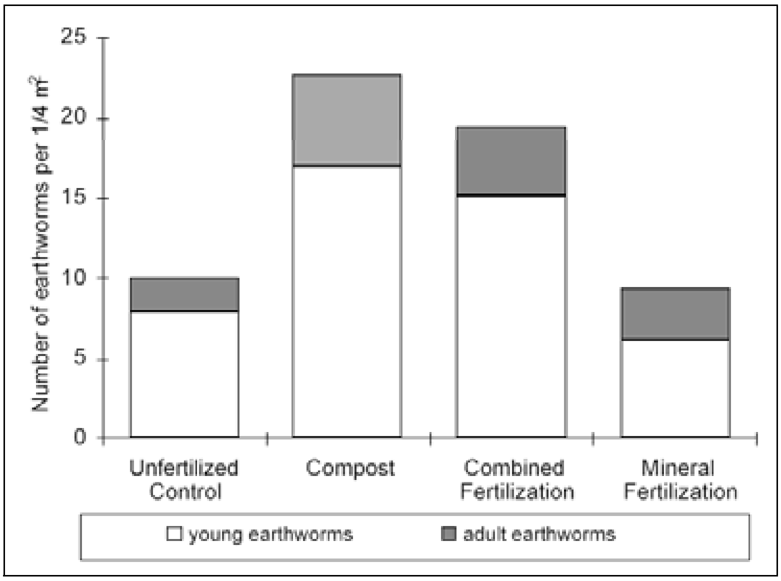


FIGURE 3-47: ABUNDANCES OF YOUNG AND ADULT EARTHWORMS AS A RESULT OF THE FERTILISATION SYSTEM (HARTL & ERHART (1998)

The abundance of earthworms reacts distinctly positive on the application of organic fertilisers. Bode (1998[SP495]) proved that a small application of ca. 250 Kg. C ha^{-1} liquid manure caused already a distinct increase of abundance, as the easily soluble C-components of liquid manure can be utilised well. Even after application of other organic fertilisers like manure (Whalen et al., 1998[SP496]) and compost (Hartl & Erhart, 1998[SP497] – see figure 3-29; Peres et al., 1998[SP498]) the abundance of earthworms increased, whereas mineral fertilisation showed no positive effects compared with a not fertilised variant, even though over mineral fertilisation and the application of organic matter in form of farm waste was increased, too, (Bode, 1998[SP499]; Hartl & Ehrhart, 1998). The field trial of Hartl & Erhart (1998[SP500]) showed an increase of earthworm population at the biowaste compost treatments contrary to 0 to NPK variants of ca. 10 earthworms per 1/4 m² to > 20 (see figure 3-29).

The compost fertilisation of the test of Peres et al. (1998[SP501]) lead to an additional increase of the number of species.

Christiaens et al. (2003[FA502]) showed in a statistical field trial with maize on a sandy loam soil that both annually applied compost plots (22,5 Mg ha^{-1}) and the bi-annual applications (45 Mg ha^{-1}) contrary to mineral and slurry variants effected a highly significant increase of count and mass of earthworms.

TABLE 3-40: BIOMASS AND NUMBER OF EARTHWORMS IN JULY 2001, FOLLOWING FOUR YEARS OF ORGANIC TREATMENT (CHRISTIAENS ET AL., 2003)

	S -			S+			Stat. significance	
	C-	C+	C++	C-	C+	C++	S- / S+	C-/C+/C++
Mass (Kg ha^{-1})	55.7 b*	138.2 a	116.9 a	84.0 b	130.7 a	105.2 a	NS	***
Number (1000 ha^{-1})	315.6 c	1008.9 a	608.9 b	422.2 c	1031.1 a	608.9 b	NS	***

* Within a row, values with the same letter belong to one homogenous group (Newman-Keuls test)

S+ and S- = yearly slurry application or not; C+: yearly application of VFG compost at 22.5 Mg ha^{-1}; C++: 45 Mg VFG compost ha^{-1}, every two years; C-: no compost

The **Mesofauna** is also positively influenced by the application of organic fertiliser. Idinger & Kromp (1997[SP503]) proved an increase of Collemboles, Saprophages and Nematodes which were partly attributed to compost, partly have been encouraged in their reproduction by the applied organic substance. The number of arthropodes and some parasites increased, too, as these as predators profited by a higher amount of prey in the organic fertilised soil. The mesofauna can be encouraged indirectly by the increase of earthworm abundance. Hamilton & Sillmann (1989[SP504]) und Loranger et al. (1998[SP505]) found an increased number of species and individuals of micro-arthropodes in areas with a high amount of earthworms compared with areas with a low stock density. A possible reason could be a mobilisation of food reserves for meso fauna by earthworms and their positive influence on the pore volume, as the earthworm pores are serving as habitat for micro-arthropodes and guarantee an improved air and water household.

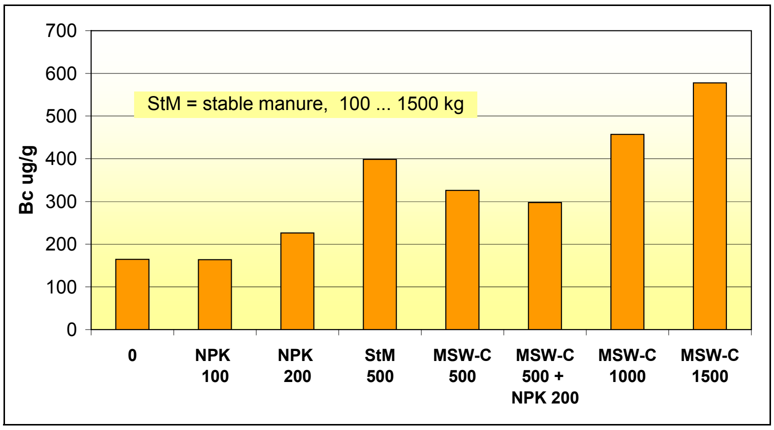


FIGURE 3-48: IMPACT OF MINERAL AND ORGANIC AMENDMENTS ON MICROBIAL BIOMASS (LEITA ET AL., 1999[SP506])

Leita et al. (1999) used as index soil microbial biomass (B_C in µg g^{-1} soil following the fumigation method) to observe the influence of a range of mineral and organic additions on the soil microorganisms. The results shown in Figure 3-48 compare the microbial response to different levels of inorganic fertiliser additions, stable manure and compost derived from Municipal Solid Waste. These results clearly illustrate, for this soil, the marked positive impact on soil microbial activity of adding organic based nutrient sources to the soil.

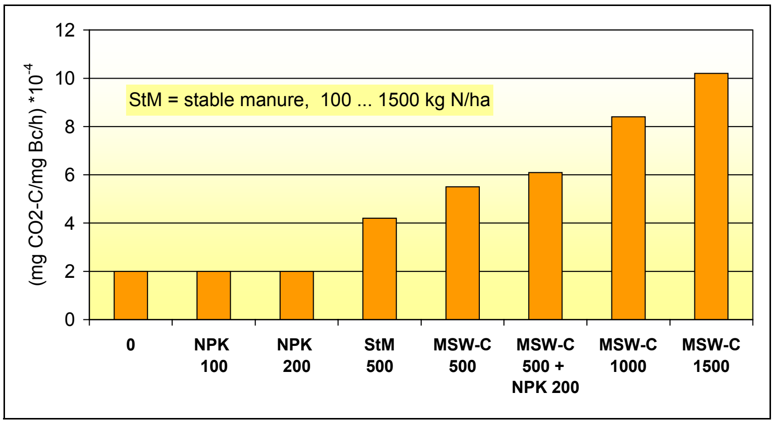


FIGURE 3-49: IMPACT OF MINERAL AND ORGANIC AMENDMENTS ON METABOLIC QUOTIENT QCO_2 (LEITA ET AL., 1999)

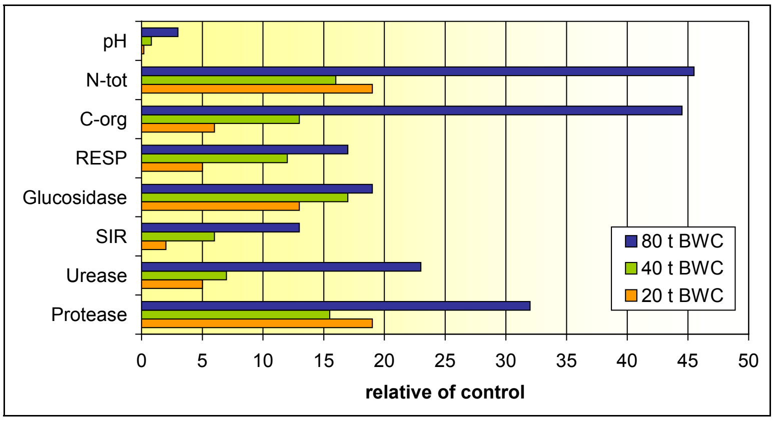
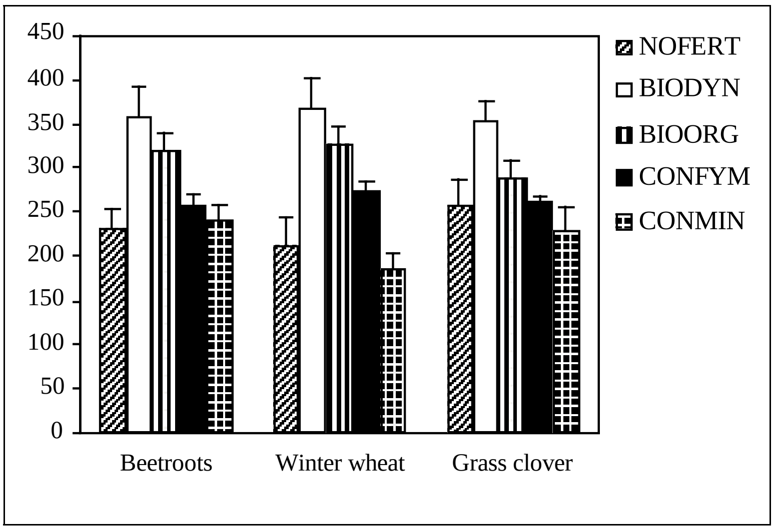


FIGURE 3-50: EFFECT OF COMPOST APPLICATION ON SOIL QUALITY PARAMETER (SCHWAIGER & WIESHOFER, 1996)



NOFERT = unfertilised control, BIODYN = bio-dynamic (manure compost), BIOORG = bio-organic (rotted manure), CONFYM = conventional with mineral fertilisers plus manure, CONMIN = conventional without manure (exclusively mineral fertilised). Error bars = standard error of means. n = 4.

FIGURE 3-51: SOIL MICROBIAL BIOMASS (MG C_{MIC} KG SOIL^{-1}) UNDER THREE CROPS AFTER PRACTISING FOUR FARMING SYSTEMS FOR THREE CROP ROTATIONS. (MÄDER, 2003)

In the same study Leita et al. (1999) used the Metabolic Quotient (qCO_2 = mg CO_2-C * mg Bc^{-1} * h^{-1}) which showed a similar marked influence of increasing the levels of organic materials (in terms of their Nitrogen equivalent values), with almost no response evident when inorganic NPK fertilisers are added at the equivalent rates of 100 and 200 Kg N ha^{-1} (Figure 3-49).

Schwaiger and Wieshofer (1996[SP507]) used a wide range of indicators of soil quality and microbial activity to illustrate the impact of three rates of application (20, 40 and 80 Mg ha^{-1}) of waste derived compost when compared to a soil with no additions. The additions resulted in changes in all properties (the impact on soil pH was minimal for the 20 Mg ha^{-1} treatment), with particularly marked changes for the enzyme activity and Total Nitrogen and Organic Carbon in the system (Figure 3-50). Given the amounts of waste derived compost added the increases in Nitrogen and carbon are not surprising, however the increased enzyme activity suggests some considerable benefit to the overall microbial activity and the improvement of the overall soil health.

A statistical field experiment which compared biological with conventional cultivation systems since 21 years proved the predominance of compost in the essential indicators for soil health and fertility even effective against partly rotted manure. Fully composted manure achieved the highest microbial biomass, earthworm biomass and an increased settlement of Mycorrhizae at the roots (Mäder et al., 2000[FA508]).

Soil fertility was enhanced in the organic plots compared to the conventional plots as indicated by a higher microbial biomass, earthworm biomass and an enhanced mycorrhizal root colonisation (Mäder et al., 2000). Microbial biomass and activity increased in the order:

CONMIN < CONFYM < BIOORG < BIODYN (Figure 3-51). Moreover, the functional diversity of soil microorganisms and their efficiency to metabolise organic carbon sources was increased in the organically fertilised systems with highest values in the compost manured BIODYN plots (Fließbach et al., 2000). The authors found a positive correlation between aggregate stability and microbial biomass ($r = 0.68$, $p < 0.05$), showing the importance of soil microorganisms in soil structure formation. The results are encouraging regarding soil aggregate stability and microbial phosphorus delivery for crops, which were found to be highest in the compost manured plots.

The test results for the consequences of adequate compost management on soil organisms and the biological activity can be summarised as follows:

- Microbiological parameter
  - In general higher bilogical activity
  - Mostly increase of the microbial biomass
  - Increase of the Dehydrogenase activity
  - Mostly increase of the Protease activity
  - Mostly increase of Urease
  - SIR and β-Glucosidase activity: step-by-step increase with increasing compost application compared to not fertilised plots
  - Respiration: significant activity increase
- Soil fauna
  - Higher number of species by compost fertilisation
  - Higher population of earthworms by compost fertilisation

The positive effect of compost fertilisation on the occurrence, the activity, density and the diversity of species of earthworms and benefitial epigeic athropodes can be concluded in all of the research papers connected with this topic. However, it must be considered that in experimental trials comparing biological cropping system with conventional ones the use of pesticides with toxicological impacts may as such lead to a reduction of the population of soil biota.

3.9.6.1 Effect of compost application on soil biology– tabular survey

TABLE 3-41: EFFECT OF COMPOST APPLICATION ON SOIL (MICRO) BIOLOGICAL ACTIVITY– TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Influence on Soil Microbiology				
Bachinger et al., 1992[SP509]	Loamy sand, field trial, since 1980; Corg, N-reaction, dehydrogenase (DHA), proteaseactivity, SIR, rootgrowth, yield, CR: W-R, SW, Pot	NPK, MC + LM_U, MC + LM_U + bio-dynamic Comp and (liquid)preparations; 3 fertilisation levels: cereal/rootcrops: 60/50 Kg N ha^{-1}, 100 Kg N ha^{-1}, 140/150 Kg N ha^{-1}	Protease activity, DHA and microbial biomasse: clearly increased with organic fertilisation compared to NPK, no influence of the fertilisation intensity. Only with DHA sign. difference between MC + LM_U and MC + LM_U + biodynamic Comp and preparations.	
von Boguslawsky & Lieres, 1997[SP510]	Organic long-term fertilisation trial 1954 – 1990, effects of 6 types of org. fert. in comb. With min. fertilisation soil: deep lessivé on loess	(1) no organic fertilisation . (2) 60 dt ha^{-1} St (21-78-8) (3) 250 dt ha^{-1} Comp (106-93-40) (4) 300 dt ha^{-1} RotM (119-208-33) (5) 300 dt ha^{-1} StoM (144-262-51) (6) 250 dt ha^{-1} packed M (162-286-46) (7) 17 temp sheepfold (359-341-49) in combination with min. fertilisation	Dehydrogenase activity for StoM and St increased.	
Bragato et al., 1998[SP511]	Silty loam, 5 years after application determination of DTPA-axtractable metals, Corg in soil and C of the microbial biomass (MBC)	since 1989 7,5 resp. 15 Mg ha^{-1} concentrated resp. concentrated and composted Slu	No difference in MBC at 7,5 Mg ha^{-1}, but increase of 27 % at 15 Mg ha^{-1}. DTPA-extractable Zn was correlated with MBC.	
Cole et al., 1994[SP512]	Pesticide contaminated soil (22 pesticides) blended with uncontaminated soil and Comp; M, 15 cm pots, greenhouse; bacteria- and fungal cultures from soil and rhizoshere after collection in buffersolution on agar; dehydrogenase activity	GWC, control uncontaminated, blends: 0, 1,5, 6, 12,5 and 50 % w/w	Fungal- and bacterial populations of 100.000 up to several billionen units/g root; sign. increase of crop yield and bacterial populations in Comp containing blends, in comparison to contaminated soils, populations in soil-blend not affected. Fungal populations in Comp variations with and without plants sign. higher than in contaminated soils, dehydrogenase-activity ***sign***. higher in Comp	

Authors	Experimental Design	Fertilisation	Results	Remarks
Influence on Soil Microbiology				
			blends than in soil blends.	
Cole et al., 1995[SP513]	silty soil contaminated with pesticides	Contaminated soil was blended with uncontaminated soil resp. with GWC (0; 1,5; 6; 12,5; 25; 50; 100 %).	Microbial activity (dehydrogenase-activity) sign.*higher* in Comp variations than in uncontaminated soils.	dehydrogenase activity ↑
Gattinger et al., 1997[SP514]	Incubation, MBC, PL-P (Gesamt-Phospholipidphosphate), CO2-respiration, FDA-HR (fluorescin-diacetat-hydrolysis)	11 diff. Comp (BW, GW, CM), 1 – 3 year stockpile of Comp, comparison to fresh Comp	Microbial biomass and activity decreases with increasing Comp age. Highest biomass content in MC_C. Higher specific activity (= activity rate to biomass unit) in BWC and GWC.	
Herrero et al. (1998[SP515])	Greenhouse, 4 months, sandy-loamy soil; yield of ryegrass, analysis of residual min. N-content, alkalyne-phosphatase level and dehydrogenase-activity in soils.	14 different organic products (Comp, Slu, f.m.) 25 and 50 Mg ha^{-1} d.m.	General increase in yield, high negative correlation between NH_4-N and dehydrogenase activity; alcalyne phosphatase and dehydrogenase activity increased independently of application rate.	
Joergensen et al., 1996[SP516]	Incubation 50 days, C mineralization, growth of microbial biomass, aminoacids and aminosugars.	BWC, blends 10, 20, 30... 100% w/w Comp	C-mineralization: 1,6 % of Corg in soil, 3,5% in Comp. MBC: 127µg/g d.m. in soil, 764µg/g d.m. in Comp, disproportionate increase between 20 and 40%-blend. K_2SO_4-extractable C increased from 0,56% Corg of soil to 1,24 % of Corg im Kompost proportional to Comp application. Aminoacid- and Aminoacid and aminosugar content showed non-linear increase with increasing Comp content.. Ratio aminoacid-C/Aminosugar-C: 1,9% in soil, 4,7% in Comp.	
Kögel-Knabner et al., 1996[SP517]	Microcosm-trial, 18 months, 3 soils: Kippboden mine-spoil??	BWC fresh resp. mature, 100 Mg ha^{-1}	Comp application increases microbial activity in all soil-substrates, especially with immature (fresh)	mikrobielle Aktivität (DMSO-

Authors	Experimental Design	Fertilisation	Results	Remarks
Influence on Soil Microbiology				
	from opencast mining Ss, brown soil Sl2, lessivé Ut4; biomass-C (fumigation-extraction), microbial activity (DMSO-reduction)		Comp (ca 3500 to over 6000 ng DMS/g TS*h)	Reduction) ↑
Lalande et al. 1998[SP518]	Field trial, clay and sany loam, SW, MBC (Wu et al. 1990) and APA (alkaline-phosphatase-activity (Tabatabai a. Bremner 1969))	4: MC immature and mature, commercial Comp (f.m. and peat), commercial Comp (peat and shrimpwaste), AN (ammoniumnitrate 90 Kg N ha^{-1}) and control. 180 Kg N ha^{-1}, 90 kgN ha^{-1} and AN.	Clay 1994: MBC in comp variations 34 % higher than AN and 64 % höher than control. Sandy loam: sign. difference only in April 1995, no sign. differences between Comp and Comp + AN. APA sign. increased (30 %) on Comp variations compare to AN and control.	
Leifeld et al., 1999[SP519]	Microcosm-trial, 18 months loamy luvisol, sandy cambisol	BWC mature (65 Mg ha^{-1} d.m.) and immature (70 Mg ha^{-1} TM)	C-mineralization and specific respiration increase due to Comp application up to 100-fold, but also decreased quickly exponentially. Microbial biomass clearly increased (14-fold with immature (fresh) Comp), devreased again during trial period and at trial end variations with and without Comp were the same.	
Leita et al., 1999[SP520]	Field trial, sandy loam long-term effects (12 years) of Comp in comparison to NPK and MC on TOC, MBC, B_c and metabolic quotient qCO_2 as well as heavy metals – availability; random. block, 4 replications.	MWC: ca 50, 100 and 150 Mg ha^{-1}year^{-1}(= 500, 1000 and 1500 Kg N ha^{-1} and year, 0,94 % Ntot in Comp) = 2, 4 and 6-fold beyond Italian limit.	TOC: after 12 years no difference on control and NPK. f.m. (10 Mg ha^{-1} org. C) doubled TOC from 1,63 to 3,08. Comp (500 Kg MWC ha^{-1}year^{-1}= 6,8 Mg ha^{-1} organic C) increased TOC by 50 %. MBC(B_c): 163 – 226 µg g^{-1} soil on control and NPK, sign. increase with f.m. (bis 399) and Comp (to 578 µg g^{-1} -soil). Linear relation between B_c and TOC. qCO_2: increased from 2,0 mg CO_2-C mg B_c^{-1} h^{-1} 10^{-4} to 4,2 (f.m.) resp. 5,4 – 10,2 (Comp 500, 1000, 1500).	
Liu & Cole, 1996[SP521]	Greenhouse, M, 4 weeks, pesticide contaminated soil, dehydrogenaseactivity	GWC 0, 1, 5, 10, 20, 40 % Comp.	Sign. increase of dehydrogenase at 20 and 40 % Comp (18,8 times higher than in solely contaminated soil) no stimulation < 20 %.	
Mäder et al.,	Longterm field trial since 1978;	Supply of org. matter during 7	(D1): highest value for microbial biomass and (SIR)	

Authors	Experimental Design	Fertilisation	Results	Remarks
Influence on Soil Microbiology				
1995[SP522]	comparison bio-dynamc (D), organic (O) and conventional (K) cultivation (DOK-trial) CR: Pot, W-W, BR, W-W, Bar, 2x ley Luvisol on loess SIR, dehydrogenaseactivity	years (2nd CR-period): (D1): 1010 Kg ha^{-1}; (D2): 2.020 Kg ha^{-1} in form of MC_C Results at the end of the 2nd CR-period; (O1) & (O2): RotM; (K1) & (K2): StabM ca 1.000 resp. 2.000 Kg ha^{-1} each.	dehydrogenase activity compared to (O) and (Comp) and especially the unfertilized control.	
Marinari et al., 1996[SP523]	Field trial, M, green harvest after 150 days calcareous, humic soil	NPK. (100 Kg N ha^{-1}), StabM (30 Mg ha^{-1}) as well as MC_C (60 Mg ha^{-1}) (both incorporated $10^{-1}5$ cm). Comp amounts equivalent to min.N-variations. Combination: MC_C + NPK (30 Mg MC_C + 145 Kg NH4NO3 ha^{-1} (50 Kg N). 1 control. All fertilisation variations with and without herbezide application.	3 months after seeding (during bloom) sign. decrease of MBC, towards end of vegetation period increase again.	
Mats & Lennart, 1999[SP524]	Fieltrial, 16 years, long-term effects on microorgansims, basal respiration and SIR, heterotrophic N-fixation, N-mineralization, ammoniumoxidationrate, denitrification, phosphataseactivity	Continuous Slu application 0, 1 and 3 Mg d.m. ha^{-1}/year all 4 years, + min. fertilisation	Generally higher biolog. activity, slight increase of pH-value, no clear influence on basal respiration, increasing trend on SIR, N-mineralization increased with Slu ammounts, negative influence on nitrification in soil. No clearly negatice influence on microorganisms.	
Moreno et al., 1998[SP525]	Greenhouse lettuce, lettuce (4 months) and Bar (7Monate), 4 replications., very low SOM, container with 20 Kg soil, HM-content, OM-content and enzymatic activity	SSC partially enriched with heavy metals, composted with Bar-straw, 20 and 80 Mg ha^{-1}, control: soil without Comp, standard NPK-fertilisation	*Urease:* sign. increase after cultivation (up to ca. 2 µmol $NH_2g^{-1}h^{-1}$) in comparison to control (ca 0,25 µmol $NH_2g^{-1}h^{-1}$); *Protease-BAA activity:* Sign. increase only with high applications. *Phosphatase-activity:* increase before and after cultivation, especially with high application rates in dependency of plant types; *β-glucosidase-activity:* sign. increase with high	

Authors	Experimental Design	Fertilisation	Results	Remarks
Influence on Soil Microbiology				
			application rates with uncomtaminated Comp.	
Niklasch & Joergensen, 2001[SP526]	Incubation experiment, silty loam, respiration and biomass of microorganisms	BAK, GGK (green waste/grass), peat, standard application rates: 0,5%, 1,0%, 1,5%, 2,0%	Increase of CO_2, released during incubation, with all 3 substrates; increase with higher substrate concentration; decrease of substrate mineralized to CO_2, with increasing addition. BWC increased biomass-C-content within 25 days, GWC: biomass-C-content after 92 days almost the same as with BWC, sign. increase with increasing Comp application rate, peat: no influence on biomass-C day 25: qCO_2-values: BWC>GWC>peat, day 92: GWC>peat>BWC.	
Pascual et al., 1997[SP527]	Incubation trial, clayloam with low OM-content (0,4 %); MBC, basalrespiration, ratio biomasse-C/total org. C and qCO_2 (metabolic quotient)	MWC (frisch), Slu, Comp; enrichment in SOM 0,5 % (low application rate) resp. 1,5 % (high application rate)	Sign. TOC-increase independent of application rate, sign. increase of biomass-C and the basal respiration in dependency of the application; biggest difference of biomass-C/TOC ratio at the beginning and end of the incubation period with fresh MWC application; qCO_2 increased from 4,4, especially with the addition of fresh org. materials, to 8,7, all biological parameters show a decreasing tendency over time.	
Pfotzer & Schüler, 1997[SP528]	Long-term field trial, Pot, fluorescin-diacetate (FDA) hydrolysis and feeding activity with bait-lamina-test after Törne (1990[SP529]), populationdesity of collembola and acarina	MC with and without hornmeal, BWC (60 Mg ha^{-1} f.m.), hornmeal (0,6 Mg ha^{-1}), NPK	After cultivation, fertilisation and Pot planting FDA-activity and feeding activity on comp variations sign. higher than control.	
Popp et al, 1996[SP530]	3 trials, Mitscherlichvessel, silty loam, green O. Various chemical parameters, biolog. parameters: T_{max} (self-heating after BGK 1994), RI $_{max}$ (respiration intensity), pH_{5h}, Eh_{5h} (redoxpotential after 5 h	90 diff. Comp, biowaste 0 – 100%, greenwaste 0 – 100%, various additives	Good control of rotting progess with AI $_{max}$, close correlation to yield only with pH_{5h}, improvement of accuracy of yield prognosis by multiple regresssion anylsis of several chemical and biological parameters.	

Authors	Experimental Design	Fertilisation	Results	Remarks
Influence on Soil Microbiology				
	anaerobic incubation), DMSO (dimethylsulfoxireduction)			
Postma & Kok, 2003[SP531]	Sandy soil + additives 14 days incubation at 18°C; platecount of 1. semiselective media, 2. ecoplates (BIOLOG) and 3. genetic community profiling (PCR-DGGE)	0,4% papercellulose, 1% SMC, 1% GC, GWC	No influence on total cell count No difference with aerobic bacteria and actinomycetea; pseudomonas flourescens increased with cellulose; fungi increased with cellulose and SMC, cellulose and SMC differ from GC in utilization of C-source (BIOLOG)	
Schwaiger, 1996[SP532] Siehe Schwaiger & Wieshofer, 1996[SP533]	Field trial, 4 years Fertilzation in fall, soil sampling in spring; Urease, protease, β-glucosidase and alkaline-phosphatase Respiration after glucoseaddition (SIR)	BWC 3 (45 Mg ha^{-1}) N1 BWC 3 (45 Mg ha^{-1} +25 Kg N ha^{-1}) N1 BWC 2 (15 Mg ha^{-1} + N) N3 (75 resp. 120 Kg N ha^{-1}) control	1994: high *SIR*, afterwards waste, at trial finish higher soil-microbiological activity with BWC3, N1BWC3 and N1BWC2 in comparison to N3 and control; *β-Glucosidase* and *alcaline-phosphatase* seem to be more strongly influenced through FF; *Urease* and *protease*: decline (climate, FF and with protease difficulties during reduction of the highmolecular components of Comp), but 1996 sign. highest activity on the Comp fertilized plots.	
Schwaiger & Wieshofer, 1996[SP534] Siehe Wieshofer 1993	1990 – 1996, largeparcel-field trial (4 var., 3 replications.), 3 examinationdates each CR: W-W, W-R, W-R yield, soil physical and chemical data, enzymeactivity (urease, β-glucosidase and protease), respiration and respiration after glucoseaddition (SIR) calcareous grey alluvial soil, sandy to loamy silt, CR: W-W – W-R – W-R – So -	BWC20, BWC40, BWC80 (Mg ha^{-1}) during the years 1989, 1991 and 1993 in fall each control	During the initial trial years no major differences; 1996 clear graduation of soil microbiological parameters already; *Urease*: increase of 60% (1990^{-1}996); *SIR und β-Glucosidase*: graduated increase compared to control (1996); *Protease*: increase over the trial years, 1996 sign. verification of BWC variations; *Respiration*: sign. increase in activity (BWC80) Close connection with high C_{org} and N_{tot} content.	Increase of microbiological actiivity on control, which can be explained by a change to bio-organic cultivation (1989)

Authors	Experimental Design	Fertilisation	Results	Remarks
Influence on Soil Microbiology				
	SF-O-W-R			
Selivanovskaya et al., 2001[SP535]	Field trial, random. block, 4 replications., Bar, grey forest soil	Untreated Slu, anaerobically treated Slu (10 Mg ha^{-1} d.m. each), SSC (30 Mg ha^{-1} d.m.); control	SSC increased microbial biomass (1,9 – 4,4-fold), basal respiration (2,3 – 6,3 fold), and N_2-fixation (2,1 – 35 fold) in comparison to control. Anaerobically treated SSC has no influence on microbial biomass and -activity. Untreated SSC leads to a sign. Reduction of N_2-fixation.	
Serra-Wittling et al., 1996[SP536]	Incubation trial, loamy soil, water retention graphs, CO2-measurement, 9 enzymes, enzymeactivity in activity units (A.U.) per g d.m..	MSW Comp from source separated collection, soil/Comp to 0, 10, 30 and 100 % Comp	Microbial activity sign. increased. After Comp application only a few enzyme activities increased, after 189 days most enzyme activities increased.	
Shindo, 1992[SP537]	Incubation experiment, 7 weeks, highlandsoil	StoM-RiceSt-Compost	Adenosine de-aminase, protease, ß-acetylglucosaminidase through permanent Comp applications clearly increased. High correlation between mineralised N and protease resp. acetylglucosaminidase.	
Steinlechner et al., 1996[SP538]	Sandy loam, inhomogenous, biol.	MC(172 Kg N ha^{-1}) and RotM (93 Kg N ha^{-1}) 1995	No sign. difference through fertilisation.	urease, protease, dehydrogenase, basal respiration, SIR, phosphomonoesterase
Timmermann et al., 2003[SP539]	Long-term compost experiment (8 resp. 5 years): duofactorial split-plot facility with 12 variations at 4 replications. random. → 48 plots per experiment 6 sites : lS, uL, uL, utL, uL, sL CR: M – W-W – W-Bar	Comp application: 0; 5; 10; 20 Mg ha^{-1} N-supplementation level N0: no additional N-application level N1: 50 % of the optimal N-application level N2: 100 % of the optimal N- application on basis of the Nmin-content of the soil as well as further aspects, like	The differences in activity compared to control are clearly higher on plots without N application than the optimally fertilzed ones. Site with light soil: effect of Comp application on microbial biomass evident. Dependency of microbial biomass on Comp application rate differs on the various sites. Cmic/Corg-ratio: increase of microbial biomass through Comp application on all sites; mostly	

Authors	Experimental Design	Fertilisation	Results	Remarks
Influence on Soil Microbiology				
		preliminary crop etc. (comp. nitrateinformationsservice - NIS).	positive linear correlation; increase of microbial biomass on the variations without additional N-fertilisation. N-application has no beneficial effect on biomass activity. DHA/Corg- ratio in mean of sites, tendency towards an increase with Comp application are more evident than the Cmic/Corg-ratio.	
Valdrighi et al., 1996[SP540]	Pot-trial, sandy soil, chicory, microbial examination after 7, 30, 60, 90 and 120 days: total count aerobic bacteria, actinomyces and fungi	a) Comp-humic-acids at application rates of 0, 250, 500, 1000, 2000, 4000, 8000 mg/Kg soil. b) block with KCl-solution at the same application rates as Comp-humicacids. c)Tween 80 with 0, 100, 200, 1000, 2000 mg/Kg soil. d) Tween 80 combined with Hoagland's mineralsolution at a ration of 10:100. e) Comp-humic-acids 0, 1000, 2000 mg/Kg soil with 10 % Hoagland's mineralsolution.	Heterotrophic and chemolytotrophic bacteria react positively on the addition of humic acids: generally on Comp humic acids, ammonium-oxidizing autotrophic, nitrit-oxidizing autotrophic bacteria: the higher the application rate, the higher the bacterial count, but not after 120 days any more, similar situation with (e, c, d). Higher count of actinomycetes and cellulolytes MO after 60 and 90 days (a, e). No change on filamentous fungi count.	
Weissteiner, 2001[SP541]	1993 – 1999, loamy silt CR: Corn-M – So – W-W –W-Bar – Bar – FP – WRa – Corn-M –W-W,	BWC/MC some +/– compoststarterbacteria [MC_B], 12,5 – 24 Mg d.m. ha^{-1} (= 21 – 38,4 Mg f.m.) and year, 7 variations; (with and without min. NPK-supplementation, with and without application of chemical-synthetic fertilizers), standard=customary, conventional, (NPK without	*No sign*. differences.	Very high application rates! alc. phosphatase, xylanase, biomass-N

Authors	Experimental Design	Fertilisation	Results	Remarks
Influence on Soil Microbiology				
		compost)		
Wieshofer, 1994[SP542] Siehe Schwaiger & Wieshofer, 1996[SP543]	1990 – 1992, large parcel trail-field trial (5 var., 3 replications.), 3 examination dates each yield, soil-physical and chemical dat, enzymeactivity (urease, β-glucosidase and protease), respiration and respiration after glucosaddition (SIR) calcareous, grey alluvial soil, sandy to loamy silt, CR: W-W – W-R - W-R	BWC20, BWC40, BWC80 (Mg ha^{-1}) in 2 year intervals MC_H (1989: 20t ha^{-1}, 1991: 40t ha^{-1}) control	SIR increase of biochemichal conversion through Comp application evident in comparison to control; Mc_P since 1991 on same level as BWC; Ureaseprocess inconsistent until 1991, then increase in activity on all trial sites, MC_P is the highest (urea); Protease-activity increased after each fertilizer application, increase on all variations over the years; β-glucosidase-activity clearly raised in 1992, especially MC_P in comparison to control (Str).	1989 change to organic cultivation; The increase, induced by the Comp application detectable during 3rd trial year

TABLE 3-42: EFFECT OF COMPOST APPLICATION ON SOIL FAUNA– TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Effects on Soil Fauna				
Christiaens et al., 2003[SP544]	Blockfacility with 3 replications. 3 years Sil-M	Combination: with/without Slu_C; with/without BWC; 0N 100N 200N	No sign influence of min. fertilisation and Slu-application on count and biomass of earth worms; Comp application → earthworms sign. higher in count and biomass	earthworms
Hartl & Erhart, 1998[SP545]	STIKO-trial since 1992; CR: W-R, Pot, W W, O, Sp , calcareous grey alluvial soil; sandy/loamy silt	BWC 12,5, 22,5 and 32,5 Mg f.m. ha^{-1} and Jahr, NPK according to crop demand/fertilisation recommendation combined fertilisation Comp+min.N-supplementation	Increased earthworm density on BWC variations in comparison to control resp NPK-sites (increase from ca. 10 worms per 1/4 m^2 to > 20).	earthworms
Pfiffner et al., 1995a[SP546]	DOK-trial since 1978, lessivé on loess, blocktrial, 4 replications., 3 sevenyear CR: (2xley, Pot, W-W, Ca resp. BR, W-W, W-Bar);	D=bio-dynamic; O=organic, K=conventional, control: 0-fertilisation , NPK; StabM and Slu 1,2 DLU ha^{-1}, since 1992 1,4 DLU ha^{-1}; in variation D composted	1990 and 1992: sign. higher earthworm-biomass on D, O 7%, K 31 % lower. Earthworm density and greater presence of anecic earthworm species on organically cultivated sites. Chemical plant protection causes a significant reduction of earthworm population.	earthworms
Pfiffner et al., 1995b[SP547]	same as above	same as above	1988, 1990, 1991:. 93 % (D) resp 88% (O) greater presence of anecic beneficial arthropods than in conventional variations. Density of activity of ground beetles, rove beetles and spiders on organically cultivated sites sign. higher (K: 50 % reduced). Bio-diversity: D: 18 – 24 species; O: 19 – 22, K: 13 – 16.	Ground beetles, rove beetles, spiders
Pfotzer & Schüler, 1997[SP548]	Long-term field trial, Pot, fluorescin-diacetate (FDA) hydrolysis and feedingactivity with bait-lamina-test after Törne (1990), Populationdensity of collembolen and acarina	MC with/without hornmeal, BWC (60 Mg ha^{-1} f.m.), hornmeal (0,6 Mg ha^{-1}), NPK	After cultivation, fertilisation and Pot-planting, FDA-activity and feeding activity (mainly microarthropods) sign. higher on Comp plots compared to control.	microarthropods

Authors	Experimental Design	Fertilisation	Results	Remarks
Effects on Soil Fauna				
Steinlechner et al., 1996[SP549]	Sandy loam, inhomogenous, biol.	MC(172 Kg N ha^{-1}) and RotM (93 Kg N ha^{-1}) 1995	Twice the Acari- resp. collembola count sign. in comparison to control, on one site sign. higher collembola count than on Comp variation.	acari, collembola
Steinlechner et al., 1996[SP550]	Loamy fine sand, inhomogenous, biolog.	Basis 2 LU	*Sign. higher* collembolan count on RotM plot.	acari, collembola

3.10 Phytosanitary effects of compost [2]

3.10.1 Introduction

The phenomenon of compost being able to suppress soil-borne plant diseases is known since the beginning of the nineteen sixties of the last century(Bruns, 1996[SP551]; Seidel, 1961[SP552]; Reinmuth, 1963[SP553]; Bochow, 1968 a[SP554], 1968 b[SP555]; Bochow & Seidel, 1964[SP556]).. A systematic research work about the suppressive effects of composts against soil-borne pathogens has been realised since the seventies. Looking for alternative material for peat US scientists found the suppressive effects of different composted bark products. (Hoitink, 1980[SP557])

The mechanism of biological control is based on

- competition,
- antibiosis and
- hyper-parasitism (Hoitink et al., 1996[SP558])

Hoitink, Stone et al. (1997[SP559]) differentiate between „general“ and “specific “suppression effects. Suppression against *pythium* and *phytophthora* is ranking among the “general” type, those against *rhizoctonia* among the “specific” types. Following these authors the mechanism of suppression is based on microbiological interactions like competition, antibiosis (Hoitink, Van Doren et al. 1977[SP560]; Theodore & Toribio 1995[SP561]) hyper-paritism and induced resistance. Fuchs (1996[SP562]) himself differentiates between „quantitative suppression“ which can be found through the great number of microorganisms in fresh compost and “qualitative suppression”. The latter is characterised by the fact that only a small but efficient number of antagonists are developing during the maturation phase.

In order to achieve consistent suppression effects a controlled inoculation has to be carried out in practice. Especially important hereby is the stability of the compost. Pathogens are spawning in immature composts and are suppressed in mature composts. However, extremely stabilised (→ mineralised) organic material does not support the activity of bio-controlled materials. The period when compost is applied in relation to the time of planting has to be considered together with the salt content and the release of nutrients. (Hoitink et al., 1996[SP563])

The effects of composting on plant health cannot be reduced only to the destruction of pathogens. Quite a number of examples exist where composts are able to protect different crops from several pathogens. These effects are not only restricted to laboratory research but can also be proved in practice.

[2] *This chapter is generally dealing with the literature survey of Fuchs (2003) „ Influence of compost application on plant health“.*

3.10.2 Mechanisms of disease suppressing effects

Regarding the target organisms the protective mechanisms of compost can differentiate (Fuchs, 2003[SP564]). Thus, *Rhizoctonia* suppression of a mixed waste compost was destroyed through heat treatment, whereas *Fusarium* suppression of the same compost was not damaged (Cohen, Chefetz et al., 1998[SP565]). It seems that microbes are responsible for *Rhizoctonia* suppression, whereas heat-resistant fungistatic substances in compost are possibly effective against *Fusarium sp.* (Cohen, Chefetz et al., 1998[SP566]).

3.10.2.1 Micro-biological parameter

The main protection mechanism against plant diseases seems, according to Fuchs 2003[SP567], to be based on the microbial activity of composts (Nelson & Hoitink, 1983[SP568]; Hoitink, Boehm et al., 1993[SP569]; Tilston, Pitt et al. 2002[SP570]).

- Numerous publications show that a heat treatment which destroys the microflora of composts also inactivates the suppressive effects (Nelson & Hoitink, 1983[SP571]; Hadar & Mandelbaum, 1986[SP572]; Trillas-Gay, Hoitink et al. 1986[SP573]; Hardy & Sivasithamparam 1991[SP574]; Brunner & Seemuller 1993[SP575]; Theodore & Toribio 1995[SP576]; Serra, Houot et al. 1996[SP577]; Ringer, Millner et al. 1997[SP578]; Fuchs 2002[SP579]; Tilston, Pitt et al. 2002[SP580]). Only little exceptions are known (Filippi & Bagnoli 1992[SP581]). In this case it was found that compost from poplar barks protects carnations from tracheofusariosis in substrates with poor nitrogen contents if it is sterilised.
- Numerous reports show that the suppressive effect of composts and their microbiological acitivities are correlating with the hydrolysis velocity of acetate fluorescin (Chen, Hoitink et al. 1988[SP582]; Inbar, Boehm et al. 1991[SP583]; Bruns, Ahlers et al. 1996[SP584]; Craft & Nelson 1996[SP585]; Dissanayake & Hoy 1999[SP586]).
- Various microorganisms are responsible for his biological activity.
- The efficacy of the microorganism complex of compost must be seen as a whole and not necessarily its individual components**.** Trillas-Gay, Hoitink et al. (1986[SP587]) isolated *trichoderma harzianum* and *flavobacterium balustinum* from suppressive compost. Adding both fungi to steamed not suppressive composts part of the antagonistic activity of the composts will be rebuilt. None of both fungi shows an effect if they are added alone.
- Micro-biological activity of compost and the ability to suppress diseases depend on its physiological condition**.** Different authors proved that compost setmming from the heat zone of a windrow shows a distinctly lower ability to protect plants from diseases than those from cooler areas of the windrows (Hadar & Mandelbaum, 1986[SP588]; Chen, Hoitink et al. 1987[SP589]; Chen, Hoitink et al. 1988[SP590]; Chung & Hoitink 1990[SP591]). Compost from the high temperature zone that is stored at cooler temperatures for some weeks, will become suppressive, i.e. as soon as the natural antagonists have developed sufficiently (Chen, Hoitink et al., 1988[SP592]). At the final stage of primary decomposition the fungi spectrum in the compost is relatively poor. The fungal flora of fresh composts comprises saprophytic and phytosanitary ineffective types of fungi. After maturation, however, changes in quality and quantity of the fungal flora can be recognised. Most of the dominant fungi of the matured compost showed in vitro an antagonistic effect against various pathogens (Breitenbach et al., 1998[SP593])

In certain cases composts can act directly against pathogens, i.e. reduce the survival rate of the pathogens even at absence of the host (Hoitink, Van Doren et al. 1977[SP594]; Theodore & Toribio 1995[SP595]). In other cases the compost influences the pathogenic population only when the host is present**.** The compost may prevent the growth of the pathogenic population at the presence of the host plant (Chen, Hoitink et al., 1987[SP596]).

3.10.2.2 Chemical and physical parameter

Besides biological activity certain chemical and physical properties of composts can play a certain role, at least on short terms, yet not exclusively, for the suppression potential.

- Thus the **reduction of carbon concentrations** in compost correlates with the increase of suppression (Chen, Hoitink et al. 1988[SP597]). The substrates with an increased suppression are characterised by low **nutrient availability** and a **large population of mesophilic microorganisms with a high level of activity** (Chen, Hoitink et al. 1988[SP598]).
- It seems that the **nitrate content** in the soil, besides the microbial activity of composts, plays a certain role. Ringer, Millner et al. (1997[SP599]) found more pythium symptoms in soils with a higher nitrate concentration. Similar results have been found by Filippi & Bagnoli (1992[SP600]) with carnation: poplar bark compost protects the plants from *fusarium oxysporum f.sp. dianthi*, even if they are growing in a naturally infected soil. But only if it is sterilised. It is assumed that this effect is caused on a lack of nitrogen, what probably does not allow a proper disease development. The addition of easily available nitrogen fertiliser counteracts this effect (Filippi & Bagnoli 1992[SP601]).
- In addition, the **general nutrient supply and the improvement of soil physical properties** have a favourable effect on plant health.
- Besides the nutrients the **phenol content** found apparently a certain importance. In a cress-*pythium ultimum* biotest with bark compost a correlation between phenol content and suppression was found (Erhart et al. 1999[SP602]b).

3.10.2.3 Stimulation of soil microbial activity

The mechanism of effects of composts is assumed to be based on both the own microbiological activity and the stimulation of the microbiological activity of soils (Nelson & Boehm 2002[SP603]).

According to Brito, Hadley et al. (1992[SP604]) the composts also change the number of microorganisms of the rhizosphere, but not their composition. The antagonists are particularly stimulated hereby.

3.10.3 Difference between compost and other organic fertilisers

According to Fuchs 2003[SP605] the main difference between composts and other organic fertilisers is based on the inherent microbiological composition of the populations and their activity. Sugahara & Katoh (1992[SP606]) proved that inputs of rice straw in soils are delivering energy and nutrients for pathogens and saprophytes. With applications of mature straw compost the respiratory values of the microorganisms were distinctly lower than after straw application. The risk to encourage pathogens is distinctly lower after compost application than after straw application (Sugahara & Katoh, 1992[SP607]). Nakasaki et al. (1996[SP608]) achieved similar results. In potatoes the symptoms caused by *Verticillium dahliae* and *Pratylenchus penetrans* could essentially be reduced by applying spent mushroom compost compared to straw mulch. They ascertained that spent mushroom compost increases the gas exchange of potato leaves what was not observed with straw mulch. This indicates a reduction of root infestation by *Verticillium dahliae* and/or *Pratylenchus penetrans*. (Gent, LaMondia et al. 1999[SP609]), Similar phenomena have been found with fresh and composted bark (Chung, Hoitink et al. 1988[SP610]). Fresh bark increases the incidence of *Rhizoctonia sp.* in growing media while bark composts make the substrate suppressive. The reason is probably an increased supply of cellulose through the fresh bark which Rhizoctonia can use for growth. The availability of cellulose is strongly reduced in composts. Low charges of cellulose reduced the disease while higher amounts had an increasing effect (Chung, Hoitink et al. 1988[SP611]).

3.10.4 Parameters influencing the suppressive properties of composts

The efficacy of composts can change significantly from compost to compost and from batch to batch. E.g. grass and garden composts, and composts being still in the thermophilic phase are not so efficient as mature composts from other origin in order to protect Agrositis against *Pythium sp.* (Nelson & Boehm, 2002[SP612]). Fuchs (2003[SP613]) informs about the parameters which are influencing the suppressive properties of composts.

3.10.4.1 Composition of source materials for compost production

The importance of the composition of used source materials for suppression ability of composts had been researched by several authors. According to Fuchs (2003[SP614]) no consistent results could be found to date. Ringer, Millner et al. (1997[SP615]) compared composts from different types of manure. All these composts proved to be suppressive against *Pythium ultimum* and *Rhizoctonia solani*. Nearly no differences could be observed concerning the effect with cucumber against *Rhizoctonia solani* attack. But compost produced of cow manure seemed to be more efficient against *Pythium ultimum* infestation than horse manure. The lowest suppressive effect showed compost produced from poultry manure. The efficacy of composts against *Pythium ultimum* was inversely proportional to their NO_3 contents (Ringer, Millner et al., 1997[SP616]).

According to Brunner & Seemuller (1993[SP617]) the different microflorae in green composts and from cherry tree bark are responsible for the reduction of diseases in raspberries caused by *Phytophthora fragariae var. rubi*. contrary to composts from coniferous bark which could not protect the plants.

As already mentioned the authors who researched the influence of the source materials found partly contradictory results. Walter, Frampton et al. (1995[SP618]) found a more efficient protection of peas against *Aphanomyces euteiches* with composts containing manure. This was traced back to the larger diversity of nutrients and microorganisms. Erhart et al. (1999[SP619]b) found that green compost showed a distinctly lower efficacy in order to protect cress against Pythium ultimum. On the other hand Bruns, Ahlers et al. (1996[SP620]) showed that green compost could protect peas against Pythium ultimum and tomatoes against *Phytophthora parasitica* more efficient than sheep manure compost. They concluded that this effect is related to a distinctly higher microbiological activity of green compost.

The available papers lead to the impression that the composition of the original mixture is only important in an indirect way. Physiological maturity of composts, the different microbiological composition and the nitrogen availability seem to the major parameters. Some scientists could explain the different diseases suppressing effects with these factors. Fuchs, (2003[SP621], data not published) came to the same results carried out with some hundred different composts. Hereby it was found that the addition of material containing lignine during the maturity phase alone could increase the suppression potential of composts, like e.g. hemp fibre as a peat substitute. This improvement seems to be based on a stimulation of a *trichoderma spp.* population through these composts.

Different compost fractions after screening showed a different microbial composition. According to Tilston, Pitt et al. (2002[SP622]) compost, after being screened through a 4 mm mash screen, lost its protective potential. The authors assume a possible reason in the fact that fine screened composts show a lower amount of extractable carbon. On the other hand fine screened composts contains less lignin material which is relatively rich in *Trichoderma spp*. This antagonist decomposes lignin. It seems that fine screened compost contains less *Trichoderma spp.* and therefore might be less suppressive.

3.10.4.2 Application rate

The suppressive effect on composts is mostly proportional to the rate of compost application. This could be proved without doubts by Serra, Houot et al. (1996[SP623]) at the protection of linum against *Fusarium oxysporum f.sp. lini* in natural soils with a compost application of 10, 20 and 30% mixed waste compost. Similar results found Fuchs (2002[SP624]) with different proportions of compost in growing media. Less distinct effects as related to compost rates found Walter, Frampton et al. (1995[SP625]). Suppression tests were carried out at peas and *Aphanomyces euteiches* with sterile sand and large quantities of compost. The compost portion in the sand was 25, 50, 75 and 100%. In pure sand the compost microorganisms don't meet the competition of a natural soil-borne microflora. In a microbiological sense a sand substrate with 25% compost is already well buffered. On the other hand growth inhibiting factors caused by composts on account of high salt and nutrient contents may counteract pathogen-suppressing effects.

Generally it can be concluded: the poorer the microbial status of a substrate, the lower the disease suppression effect. The amount or proportion of the applied compost is also important (Fuchs 1995[SP626]; Fuchs, 1996[SP627]; Fuchs, 2002[SP628]) as the compost microflora easily establishes itself in such substrates.

3.10.4.3 Compost maturity

Suppressive effects of composts are depending on compost maturity. Numerous authors could point out that the degradation degree of organic material can be a decisive factor (Chef, Hoitink et al. 1983[SP629]; Kuter, Hoitink et al. 1988[SP630]; Grebus et al., 1994[SP631]; Hoitink & Grebus 1994[SP632]; Fuchs, 1996[SP633]; Hoitink, Stone et al. 1997[SP634]; Cohen, Chefetz et al., 1998[SP635]; Ceuster, Hoitink et al. 1999a[SP636]; Ceuster, Hoitink et al. 1999b[SP637]; Erhart et al., 1999[SP638]b; Tilston, Pitt et al. 2002[SP639]). According to some authors only mature compost (ideal stage according to Waldow et al. (2000[SP640]): 3 – 6 months) renders the desired antiphytopathogenic effect. (Ferrara et al., 1996[SP641]; Tuitert & Bollen, 1996[SP642]; Waldow et al., 2000[SP643].)

Very young composts mostly show a low suppression (Chef, Hoitink et al. 1983[SP644]; Kuter, Hoitink et al., 1988[SP645]; Grebus et al., 1994[SP646]; Craft & Nelson 1996[SP647]; Ceuster, Hoitink et al. 1999a[SP648]; Ceuster, Hoitink et al. 1999b[SP649]; Erhart et al. 1999[SP650]b). Excessive nutrient and energy contents (glucose, amino acid etc.) of fresh organic material can suppress the production of essential enzymes of antagonists and thus distinctly impact their effectiveness (Ceuster, Hoitink et al. 1999a[SP651]; Ceuster, Hoitink et al. 1999b[SP652]). Nutrients and organic matter rich in energy can also be a nutrient source for pathogens and thus assist diseases (Hoitink & Grebus 1994[SP653]; Tuitert & Bollen, 1996[SP654]). During maturation the suppression potential increases in general (Chef, Hoitink et al. 1983[SP655]; Kuter, Hoitink et al., 1988[SP656]; Hoitink & Grebus 1994[SP657]; Craft & Nelson 1996[SP658]; Fuchs, 1996[SP659]; Ryckeboer & Coosemans 1996b[SP660]; Erhart et al. 1999[SP661]b). If maturity passes a certain stage, the organic matter is highly stabilised, whereas the microbiological activity decreases and, consequently compost is losing its suppressive effect (Boehm, Madden et al. 1993[SP662]; Hoitink & Grebus 1994[SP663]; Hoitink, Stone et al. 1997[SP664]; Tilston, Pitt et al. 2002[SP665]).

As already mentioned the suppressive effects against the different pathogens are not all based on the same microbiological mechanisms. One can distinguish between "general" and "specific" suppression (Hoitink, Stone et al. 1997[SP666]). Fuchs (1996[SP667]) differentiate between “quantitative” and “qualitative” suppression. The main causes of the different types of suppression are the microbiological populations settling in the composts, changing, however, continuously during the decomposition process. The degradation degree of organic matter affects the composition of microorganisms in the rhizosphere (Boehm, Madden et al., 1993[SP668]). There from follows that not all pathogens react in a same way on the maturity degree of composts.

Fresh compost can efficiently protect agricultural crops against *Pythium ultimum* or *Phytophthora cinnanomi* (Kuter, Hoitink et al., 1988[SP669]; Tuitert & Bollen, 1996[SP670]). A high plant protection against *Rhizoctonia solani* is usually achieved with more mature composts (Kuter, Hoitink et al., 1988[SP671]; Tuitert & Bollen, 1996[SP672]; Cohen, Chefetz et al., 1998[SP673]). An attack of *Pythium graminicola* at agrostis palustris could be avoided only with mature green composts (Craft & Nelson 1996[SP674]). However, not all of the composts show a successful suppression in an advanced maturation stage. Grebus et al. (1994[SP675]) worked with green composts showing a good general suppression. The same compost did not successfully suppress *Rhizoctonia solani*. The authors concluded that the specific Rhizoctonia antagonists were missing and thus the present microflora against rhizoctonia sp. was ineffective. The research of Ringer, Millner et al. (1997[SP676]) can be judged as an exception. Both of the researchers did not find a significant relation between the rotting duration of manure compost and their potential to protect cucumber and radishes against *Rhizoctonia solani*.

Only in some cases fresh composts perform more efficient than mature composts

For some pathogens it is still not known whether the stage of maturity of compost plays a specific role. According to Chef, Hoitink et al. (1983[SP677]) chrysanthemum and hemp will become more efficiently protected against a *Fusarium oxysporum* attack if treated with mature bark compost instead of fresh bark compost. Cohen, Chefetz et al. (1998[SP678]) could not find a correlation between the age of mixed waste compost and the protection of cotton against *Fusarium oxysporum f.sp. vasinfectum*.

A pre-condition for large scale practical utilisation of antiphytopathogenic effects is the distinct definition of the production process and the production of composts with constant properties. (Bruns, 2003[SP679]).

3.10.5 Measures to increase the disease suppressing effect of composts

Fuchs (2003[SP680]) reports about different measures in order to increase or to assure the suppression potential of composts. According to Chung, Hoitink et al. (1988[SP681]), Hoitink & Grebus (1994[SP682]) the antagonists, besides bacillus spp., are killed during the thermophilic phase and must re-establish in the succeeding process. In order to assure the quality Chung & Hoitink, (1990[SP683]) recommend inoculation of the compost with pre-selected antagonists. An inoculation with *Trichoderma harzianum* taken from the high temperature zone increases effectively the suppression of the composts (Chung & Hoitink, 1990[SP684]). The application of this antagonist taken from the mesophilic temperature zone, however shows hardly an effect. Probably, in this zone a more efficient the competition of the microorganisms (Chung & Hoitink, 1990[SP685]) can be found, whereby Trichomedia cannot establish itself easily. These results contradict the findings of Nelson, Kuter et al. (1983[SP686]). According to them *Trichoderma sp.* can develop in mature compost very well, but not in fresh compost or in peat. Not every substrate is suitable for the development of an antagonist.

Other authors have been successful with the inoculation of further antagonists. Special attention must be paid on the type of material added, in order to guarantee the freedom of pathogens and weed seeds.

In developing such these technologies and procedures the positive properties of composts might be negatively influenced. Certain nutrients (especially ammonium) and high salt contents can have a negative effect on the suppression properties of composts (Chung, Hoitink et al. 1988[SP687])

3.10.6 Long term effects / practical applications

According to Fuchs (2003[SP688]) today exist sufficient well documented experience which confirms that the positive effects of composts on the plant health are not only based on laboratory trials but are more and more acknowledged in horticultural and agricultural practice.

The effect in agricultural cropping systems, however, is not always specific, but relates generally to growth and health of plants.

It must be kept in mind that the results of pot experiments in sterile sand do not necessarily correlate with findings in the field, in both a positive and in a negative sense. Likely, growth conditions play a decisive role (temperature, air humidity, water content in the soil etc.). It can be assumed that positive effects from composts on field scale are based on a range of factors: e.g. fertilisation system (above all nitrogen), the stimulation of microbial activity of soil and compost microorganisms respectively (Craft & Nelson, 1996[SP689] cit. from Fuchs 2003[SP690]).

In Switzerland compost is successfully applied after steaming in order to revitalise the soil and to increase and assure the efficiency of the treatment for longer periods. (Fuchs, 2002[SP691])

3.10.7 Compost and induced resilience

Composts do not only influence the plant health regarding soil-borne pathogens. They are also able to increase the general state of plant health. Induced resilience seems to affect the strength of the defensive reaction of plants against infestation to a greater extent than on activating antagonists (Zhang, Dick et al. 1997[SP692]).

TABLE 3-43: EXAMPLES OF PLANT DISEASES, THE APPEARANCE OF WHICH WAS REDUCED THROUGH THE APPLICATION OF COMPOST

Pathogen	Host	Compost	Benefit	Source
Phytium ultimum	Several hosts	BAK, GSK, MK_R	Reduced infestation approx. 54 %, up to 80 % with green compost at extreme infestation	Bruns, 1996[SP693]
Phytium ssp.	Cress	21 BAK	Reduced infestation up to 87 %	Erhart & Burian, 1997[SP694]
Phytium ultimum	Cucumber	GSK	Reduced infestation up to 80 %	Waldow et al., 2000[SP695]
Pythium ultimum	Cucumber	Compost	Increase of the suppressive effect	Ferrara et al., 1996[SP696]
Pythium ultimum	Cucumbers		Induced resistance at tests with split roots, where only one part came into contact with compost. These effects are lost when composts are sterilised	Hoitink, Zhang et al. 1997[SP697], Zhang, Han et al. 1998[SP698]
P. aphanidermatum *Rhizoctonia solani*	Cucumbers Cotton		Reduction of infestation	Hadar et al. 2000[SP699], zit. in Timmermann et al. 2003

P. ultimum, *R. solani*	Pea, been, beetroot	BAK	Reduction of infestation approx. 39 % at initial compost application 32 % a 7 days retarded compost application	Schüler et al., 1989a[SP700]
P. ultimum, Rhizochtonia. solani	Beetroot bean	BAK, bark compost, MK_R	Reduction of infestation 25 – 40 %	Schüler et al., 1989b[SP701]
Pythium ultimum und Rhizoctonia solani	Vegetable cultivation and husbandry	Long-lasting application of composts from green cuttings	Reduction of soil receptivity for Pythium ultimum und Rhizoctonia solani. The effect of compost is so much higher, the more intensive the field is cultivated	Fuchs, 1995; Fuchs, 2002[SP702]
Rhizoctonia solani	Incubation test K 1 inoculated on arable plates	Solution of 7 commercial composts on arable plates	Suppressive effect by set-up of an inhibit zone by bactillus subtilis N4	Nakasaki et al., 1996[SP703]
Rhizoctonia-Krankheit	Lawn		Through inoculation with the antagonist Bacillus subtilis N4 a compost was produced, which controlled Rhizoctonia-disease	Nakasaki, Hiraoka et al. 1998[SP704]
Rhizoctonia solani	Radish plants		Protection against Rhizoctonia solani by addition of antagonistic bacteria in a growing media mixture. Bacteria will establish themselves better in sterilised bark compost than in suppressive bark compost	Kwok, Fahy et al. 1987[SP705]
Phytophthora fragariae var. rubi	Raspberries	GSK (20 l per running meter in spring and fall)	efficient control	Neuweiler & Heller 1998[SP706]
Phytophthora nicotianae		Mixed waste compost	Acromonium sp. parasitiert Phytophthora nicotianae	Widmer, Graham et al. 1998[SP707]
Phytophthora nicotiana	Citrus	Mixed waste compost	Improve growth on infected. (The effect nutrient efficiency and possibly also on improvement of the physical and chemical soil properties)	Widmer, Graham et al. 1998[SP708]
Bodenmüdigkeit	Planted young trees in old apple plants	Compost or worm humus	Significant increase of growth	Gur, Luzzati et al. 1996[SP709]
Stemphylium botryosum	*Asparagus plant*		*Reduction of infestation*	Stützel & Bloom 2000 [SP710]
Verticillium dahliae und Pratylenchus penetrans	Potatoes	Compost from mushroom waste	Reduction of the symptoms contrary to straw mulch, significant increase of the amount of marketable potatoe	LaMondia, Gent et al., 1999[SP711]
?	*?*	Compost	Alternative to methylbromid treatment	Ceuster, Hoitink et al., 1999a[SP712]; Ceuster, Hoitink et al., 1999b[SP713]
Pseudomonas syringae	Arabidopsis plants		Plants growing in compost, will be distinctly less attacked by Pseudomonas syringae than plants grown in peat	Zhang, Dick et al., 1997[SP714]
Erysiphe graminis	Barley plants		Induced resistency	Fuchs, 2002[SP715]

Erysiphe graminis f.sp. hordei	Barley plant		additive effect at combined application of compost extracts and compost application in the soil.	Budde & Weltzien 1988[SP716]
Anthraknose	Cucumbers		Induced resistency	Hoitink, Zhang et al. 1997[SP717]; Zhang, Han et al. 1998[SP718]
Plasmodiophora brassicae	Cabbage plants	Fresh composts	Protection of the plant decreases with increasing compost maturity	Ryckeboer & Coosemans 1996b[SP719]
Trichoderma asperellum,	Tomatoes		Trichoderma asperellum, affects tomatoe fusariose	Cotxarrera, Trillas et al. 2002[SP720]
Fusarium oxysporum f.sp. lini	Hemp		Compost increase in the soil the existing Fusarium oxysporum f.sp. lini effect proportionally to the compost quantity. Same effect with autoclavely treated compost in untreated soil. However not in heat treated soils. → direct activation of the natural saprophytic flora of soil is responsible for the protection effect of crop.	Serra, Houot et al. 1996[SP721]

3.10.8 Prospects and conclusions

The conclusion which Bruns (2003) presented at the symposium „ Applying Compost – Benefits and Needs“ may be placed here:

- Suppressive effects of bio- and yard waste composts produced in model or in commercial systems on *P. ultimum* could be demonstrated in standard bioassays and in practical horticulture.
- For large-scale utilisation of disease suppressive composts the production process has to be defined and a quality assessment scheme has to be developed in order to produce composts with consistent properties.
- Procedures to assess the curing state of composts and predict the interactions of plants, pathogens and beneficial micro organisms need to be developed.
- Studies on suppressive effects of compost in soils are promising. Research to increase the utilisation of suppressive composts in soils should be intensified. If this is successful composts originating from source separation could have an improved market potential.

3.10.9 Experimental results ob disease suppressing effects of compost – tabular survey

TABLE 3-44: DISEASE SUPPRESSING EFFECTS OF COMPOST – TABULAR SURVEY

Authors	Experimental Design	Fertilisation	Results	Remarks
Bollen & Volkers, 1996[SP722]	Plantpathogens in Comp, mode of transmittion and inactivation during the composting process			
Breitenbach et al., 1998[SP723]	Two composting methods (windrow composting, rottingbox), fungal spectrum recorded successively during the rottingprocess, antagonistic potential of the dominant fungal flora examined through platecount.	BWC	Frequently found antagonists, like Trichoderma or pythium oligandrum, represent antagonists of the phytopathogenic type. The fungal flora is considered harmless and phytopathogenically safe, with the exception of pythium irregulare. 9 of 15 chosen dominant fungi had an antagonistic effect against pathogens at 10 °C (6 at 20 °C). The bio-diversity in windrow system less than in rotting boxes. Narrower fungal spectrum after the prerotting process in immature (fresh) Comp. On open windrow composting the biodiversity decreased during the maturation process, with rotting boxes 2 – 3 fold increase of biodiversity.	
Bruns, 1996[SP724]	Inoculation of blended substrates with 5 resp. 15 % Comp, P. ultimum	BWC, GWC, MCc, standardized rotting process	BWC and GWC: sign. suppressive effect against P. ultimum, evident in several host plants. (suppression of ca. 54 %): with extremely infectious conditions (90 % yield loss) GWC achieved a suppression of the infection by max. 80%.	
Bruns, 2003[SP725]	k.A.	k.A.	Provisional results: slight trend on the suppressive effect of Comp in dependence of processing time. 3-6 months old Comp more effective than older Comp	
Erhart & Burian, 1997[SP726]	Incubationtest, germination- and growth test with cress	21 BWC with other organic wastes, 0, 15, 30, 50, 100 % Comp.	Pythium-infection was suppressed on 30 % -site, on all Comp-plots a reduction up to 87 % .	
Erhart et al., 1999b[SP727]	Greenhouse, random. block, Phytium ultimum, substrate in greenhouse inoculated, after 7 days planting of Pisum sativum	17 BWC, 1 barkComp, 1 grapepomaceComp	9 of 17 Comp slightly suppressive efffect, bark mulch strong suppession	

Authors	Experimental Design	Fertilisation	Results	Remarks
Ferrara et al., 1996[SP728]	pottrial, Rhizoctonia solani on beans and basil, Fusarium oxisporum on basil, antagonistic potential isolated microorganisms in vitro and in vivo (pot)	4 Comp: SSC + poplarbark, industrial sludge + poplarbark, poplarbark, MWC; 25, 50 and 100 % in soilblend	In dependency of maturity good suppressive effect from all Comp.	
Franco et al., 1996[SP729]	Alpechìn (liquid phytotoxic wasteproduct of oliveoilextraction) in Comp absorbed and incubated (12 days, 50 days), silty loam	cottonwasteComp, blends: 80:15 (v:v) Alpechìn-Boden with/without 15:5 (v:v) Comp	Toxicity neutralized through Comp application; plant development furthered; without Comp negative influence of alpechìn on soil microbial biomass.	
Gorodecki & Hadar, 1990[SP730]	pottrial	Composted grapewaste MC_R, peat	On both composts suppression of rhizoctonia solani and Sclerotium rolfsii on different crops, in comparison to peat.	
Grebus et al., 1994[SP731]		composted odiferous yardwaste trimmings	With increasing Comp maturity, stronger suppression of Pythium, susceptibility for rhizoctonia still given.	
Hoitink et al., 1996[SP732])	bibliography		Many quotations	
Hoitink et al., 1997[SP733]	bibliography		Many quotations	
Lievens et al., 2001[SP734]	Root-crevice-experiment, cucumber, Phytium ultimum single-sided inoculation, fresh- and dryweight of shoot and root after 35 days, pathogen detection.	BWC, composted farmwaste for improvement of ISR (induced systemic resistance)	Root-rot sign.reduced in gap-containers with Comp blend. Growth of Comp/substrate-combination sign. higher than the substrate/substrate-combination. Root-rot sign. lower on plants which germinated in Comp blend and were transplanted into a contaminated medium, compared to plants which germinated in an infected medium.	
Marcos et al., 1995[SP735]	Vesseltrial, silty clay, Tom	4 Comp types, good chemical properties	3 of the 4 Comp (Comp 1 suspicion of phytotoxins) increased yield in comparison to control. Regarding the microbial population only minor changes. Comp seems to support the growth of antagonists in the rhizosphere, which confirms the statement, that Comp is effective against root-pathogens.	
Maynard, 2000[SP736]	Field trial at 2 locations, 2 years, Tom, sandy loam, sandy	leafComp, 50 T/a d.m., NPK: 0, 650 and 1300 lb/a, control	Pure Comp variations had less blossom-end rot.	

Authors	Experimental Design	Fertilisation	Results	Remarks
	terracesoil, random. block, 4 replications.	1300 lb/a, cottonseedmeal 2166 lb/a		
Maynard & Hill., 2000[SP737]	Field trial, 3 years, onions, 3 replications. (1994 only 1)	Leaf- Comp 50 T/a, NPK in both variations	Depression of bacterial wet-rot through Comp application.	
Nakasaki et al., 1996[SP738]	Identification and isolation of Bacillus subtilis B 4 for the suppression of Rhizoctonia solani K1 through Comp products; in vitro			
Ryckeboer & Coosemans, 1996a[SP739]	Influence of Vegetable/Garden/Fruit Comp extracts on the motility of early stages of H. schachtii, petridishes, incubation		Sign. reduction of motility during the early stages of H. schachtii from day 1 to day 4 after application of Comp extract, in comparison to control and reference.	
Schüler et al. (1989a[SP740])	pottrial, Phytium ultimum, Rhizoctonia solani, various crops	BWC from source separated collection, 8 %, 10 %, 30 %	P. Ultimum: sign. increase of f.m.-weight; through Comp addition (8 %) to a contaminated medium at rise of healthy plants 29 % to 68 %, with 7 days delay of Comp application 12.5 – 44,5 %.	
Schüler et al., 1989b[SP741]	Vesselexperiment, sterilized sand Sand, BR, bean, inoculation with Pythium ultimum and Rhizoctonia solani	BWC, bark- and MCc, application rates 0, 8, 10, 30 % (v/v), NPK	Germination rate of BR after artificial contamination (P. ultimum) sign. higher with Comp application, most obvious with BWC, somewhat lower on bark Comp and MCc. Control no contamination: germination rate 75 – 85 %; with contamination: 30 %; with contamination and Comp: 55 – 70 %. Suppression potential of Comp sign. and clearly evident also on higher contamination rates! On comp plots the f.m.-weight, inspite of contamination, was 60 – 80 % of the fertilized non non contaminated control, without Comp only 20 %.	infection pythium ultimum, rhizoctonia solani ↓ yield ↑
Tsror, 1999[SP742]	Field trial, 2 years, Comp extract as plant protection, Alternaria solani, Tom, yield, disease expression	Comp extract (CEX), commercial MC_C : water, 1:5, incubated for 7 or 14 days. Weekly application on Tom leaves	Disease outbreak and yield sign. lower resp. higher than inoculated control, but not sign. lower resp. higher than non-inoculated control.	Infection alternaria solani ↓ yield ↑

Authors	Experimental Design	Fertilisation	Results	Remarks
Tuitert & Bollen, 1996[SP743]	Phytophtora cinnamoni, Rhizoctonia solani	GWC,. 0, 10, 20 % in clay-pearlite-substrate	20 %-substrate with mature Comp suppressed R. solani, but not the immature (fresh) Comp.	
Van Iersel, 2003[SP744]	Lysianthus 4 variantions: soil steamed/non steamed, composttea/without composttea	No information weekly application of biologically active composttea on microfarming plots	Clearly positive influence of Comp-tea-application on yield loss caused by soil borne pathogens (botrytis, myrothecium, pythium) After initial steam sterilization sustainable suppression of rootnematodes through Comp-tea-application.	
Waldow et al., 2000[SP745]	horticulture cucumber: Pythium ultimum	2 different GWC, peat with 25 and 50 % v/v Comp,	Comp reduced the outbreak of diseases (judged by f.m.-yield) up to 80 % on variations with disease pressure of 50 – 90 %. Material at an age of 3 – 6 months most effective.	
Weltzien, 1989[SP746]	Laboratory and field trial, vineyard: Plasmopara viticola, Uncinula necator, Pseudopeziza tracheiphila; Pot and Tom: Phytophtora infestans; Bar: Erysiphe graminis; SB: Erysiphe betae; cucumber: Sphaerotheca fuliginea; strawberry and beane: Botrytis cinerea	MC various animals, extracts 1:5 – 8, 15-20 °C incubated, extraction 1 – 3 days, induction time: timespan between Comp-extract application and inoculation	Effective plant protection against fungal diseases of leaves and fruit, with prophylactic application. Sign. and reproducable results under diverse conditions in laboratory, greenhouse and on fields	infection diverse fungi ↓
Workneh & van Bruggen, 1994[SP747]	Comparison microbial count and composition in the rhizosphere of Tom from 3 organic and 3 conventional farms in relation to the suppression of corky root (Pyrenochaeta lycopersici)	total count of actinomycetes, bacteria, fungi	Sign. higher population and greater diversity of actinomycetes in organic cultivation, significante correlation betw. count of cellulolytic actinomycetes and suppression of pyrenochaeta lycopersici; no sign. difference between sites regarding bacteria and fungi; sign. increased count of fluorescing pseudomona-species with organic cultivation;	

4 OUTLINE OF THE REGULATORY FRAMEWORK FOR THE USE OF COMPOST

4.1 Federal legislation

Compost Ordinance FLG. II Nr. 292/2001[SP748]: The regular compost application in agriculture is limited to an amount of 8 Mg d.m. per ha in an average of 5 years. In labelling the licensing rules for nitrogen fertilisation must be indicated as required by the Austrian Water Act. Application rates ranging beyond these regulations are only possible as waste recycling measure according to the Federal Waste Management Plan (BMLFUW, 2006[FA749]). One-time reclamation measures or specific uses in combating erosion in agriculture are limited to 160 Mg d.m. ha^{-1} and need in any case an authorisation pursuant to the water Act.

TABLE 4-1: POSSIBLE APPLICATION RATES OF COMPOST AS A PRODUCT IN SPECIFIED APPLICATION AREAS DEPENDENT ON THE QUALITY (HEAVY METAL) CLASS

Application area:		Quality Class: *class A+*	*class A*	*class B*
Agriculture	regular fertilisation	max. 8 Mg d.m. / ha and year on an average of 5 years		excluded**
Agriculture	reclamation; protection against erosion	max. 160 Mg d.m. / ha within 20 years °		excluded**
Hobby garden		Not more than 10 litre per m² and year		excluded
Plantation (plant holes)		Not more than 40 volume-%		excluded**
Landscaping (one-time application) / Reclamation on landfills		> 400 Mg d.m. / ha within 10 years	≤ 400 Mg *d.m.* / ha within 10 years*	≤ 200 Mg d.m. / ha within 10 years*
Landscaping (maintenance)		>40 Mg d.m. / ha within 3 years	≤ 40 Mg d.m. / ha within 3 years*	≤ 20 Mg d.m. / ha within 3 years*

° *If in the frame of an agricultural reclamation with compost according to Compost Ordinance these maximum amounts are spread no further compost application is allowed for a period of 20 years.*

* *If in a period of 10 years these maximum amounts for land reclamation have been applied no more maintenance applications shall be done within this period.*

** *Special rules laid down in provincial regulations on soil protection may allow the application of higher amounts respectively of class B compost in agriculture. Utilisation is subject to the Treatment Principles of the Federal Waste Management Plan* ***[see below]***

Only composts of the quality classes A+ and A are allowed to be applied in agriculture [§5]. Minimum requirements for biological agriculture is the use of *quality compost* class A+. This corresponds to the requirements of Annex II A of the EU Regulation (EC) n° 2092/91 of June 24th, 1991.

All composts – with the *exception of mixed waste composts* – are allowed to be used for ***the*** production of *manufactured soil* and *substrates (blends)* [§7]. The requirements for the quality of composts depend on the intended utilisation of the substrate. The following table describes the quality requirements for composts if used as constituent of manufactured soils and substrates in the different application areas.

TABLE 4-2 COMPOST AS CONSTITUENT IN MANUFACTURED SOILS AND COMPOST BLENDS

Intended application area of the compost blend	***Minimum Quality class***	***Additional quality requirement in depending on application [Ann. 2 part 1 Tab. 2]***	***Requirements for epidemic hygiene [Ann. 2 part1 Tab. 2a]***
„household“ [e.g. garden area, container plants, roof gardens]	„A“	„Hobby gardening“	„bag material“
„agriculture“	„A“	„Hobby gardening“	„agriculture“
Areas not provided for production of food and animal feeding	„B“	Landscaping and cultivation	Landscaping and cultivation

Treatment principles of the Federal waste management plan (BMLFUW, 2006):

The treatment principles of the Federal waste management plan define the boundary between *recycling* and *disposal* of wastes. A pre-condition for recycling must consider the *Soil Protection Acts of the provinces* and the federal *Water Act* and thus the implementation programme for the *EU Nitrates Directive*. Site and soil specific conditions must be respected. The application rate is a maximum of 16 Mg d.m. depending on the heavy metal content (for quality class A+) respectively 12 Mg d.m. (for quality class A) per ha and year for an average of five years, whereby the total amount during these 5 years must be split at least in two applications (years). For instance, this would mean that each application in the 1st and 3rd year would be 40 Mg d.m. at maximum.

Nitrogen loads free from authorisation according to the Water Act (amendment FLG. no. 252/1990 §32 (2) f)). A rhythm of a 2 to 3-years application of composts on agricultural land has proven to be practicable. However, this can induce exceedance of the maximum ‘free’ N-load of 175 respectively 210 Kg N ha^{-1} a^{-1}. The actual interpretation does not distinguish between different bonds of nitrogen in the organic matter pools and thus its availability when applied on soil.

The Austrian Action Programme for the Implementation of the EC Nitrates Directive (91/676/EWG) (BMLFUW (2006b[SP750]) is directly related to the Water Act and its principle rules for nitrogen and manure fertilisation. Regarding compost fertilisation the following principles are valid:

- The prohibition to apply manure, compost and sewage sludge compost on arable land in the time between November 30th and February 15th (an application from February 1st is allowed for: early cultures to be planted like *Durum wheat* and *spring barley,* green manure with early nitrogen consumption like rape seed and winter barley and field vegetables grown under foils)
- During the period from October 1st to November 30th the total nitrogen application is restricted to 60 Kg per hectare.
- Compost is excepted from the obligatory division of N applications of more than 100 Kg on slopes of > 10% near a water body in at least two portions.
- Maximum limit of 175 Kg nitrogen (from manure, compost, other wastes applied as fertilisers and commercial fertilisers) per hectare and year on arable land *without permanent crop coverage*
- Maximum limit of 210 Kg nitrogen per hectare and year on agricultural land *with permanent crop coverage* inclusive permanent grassland and with crop *rotations with high nitrogen demands*.
- Maximum limit of 170 Kg nitrogen to be applied per hectare and year from manure.

- Based on a approved higher nutrient demand of the crops and a preliminary authorisation pursuant § 32 Water Act 1959 these maximum limits can be passed. A surpassing of the maximum amount of nitrogen from manure is not possible.

A restriction to 170 Kg nitrogen per hectare and year applied with manure is also valid for **organic farming** pursuant to Regulation *(EG) Nr. 1804/1999*[SP751]. Annex VII of the regulation stipulates the admissible number of animals which correspond to a nitrogen amount of 170 Kg per hectar and year. As an example 2 milk cows, 6.5 breeding pigs or 230 laying hen correspond to an equivalent of 170 Kg nitrogen. On this background of the maximum limit of 170 Kg N ha^{-1} a^{-1} and considering the mobilisation potential of compost nitrogen again the question arises how to assess a the nitrogen limitation in organic farming in a correct and environmentally sound manner.

Austria's 2007-2013 rural development national strategy plan[3]:

Under priority 2 – Improvement of the Environment and Landscape the Agricultural Environmental measures are listed in detail. The basics of fertilising follow the essential main features of "Guidelines for a proper fertilising" of the BMLFUW (1999a and 2006c). As a basic principle quality compost of the quality class A is not excluded in the various programmes, thus becoming an allowed means of soil improvement. The following measures, however, regulate the abandonment of sewage sludge and composted sewage sludge:

- Abandonment of yield increasing production measures on all arable land and forage crops
- Abandonment of yield increasing production measures on all arable land (without forage crops)
- Integrated production for potatoes, sugar beets, vegetables, strawberries, medical and spice plants
- Integrated production of fruit and hop
- Integrated production of vine
- Abandonment of silage
- Cultivation of alpine pasture and grass lands
- Alpage and alpine cattle keeping
- Eco-indicator system
- Cultivation of agricultural land especially endangered by leaching
- Conservation and development of valuable areas in the sense of nature and water protection

The § 4 **Fertiliser Law (BGBl. Nr. 513/1994)** excludes waste water and wastes like sewage sludge, compost from sewage sludge, faeces and mixed waste composts from the scope. § 5(3), however, contains an authorisation to enact an ordinance on the admission of sewage sludge and compost of organic origin performing allow contamination to be applied as fertilisers. Such an Ordinance has never been published.

The **Fertiliser Ordinance** (BGBl. II Nr.100/2004) defines *„green compost"* as composted vegetable material stemming from agriculture as well as garden and park areas respectively. This is the only compost which purely or as a constituent of "*organic fertiliser*" or "*growing media*" is allowed to be used. The problem is that the minimum contents of organic matter

[3] http://land.lebensministerium.at/article/articleview/47976/1/8487

(>50% d.m.), and respectively P_2O_5-total (>1% d.m.) as required for organic fertilisers cannot be met by green composts in many cases.

4.2 Austrian Standards and Guidelines

ÖNORM S2202: Guidelines for application of composts – Part 1: Horticulture and landscape engineering and technical applications (2006-08-01): This standard states guidelines for a use-related and environmentally friendly application of compost for the production and maintenance of top soil layers for non-agricultural cultivation or technical applications in the following areas:

- Horticulture and landscaping,
- Facilities for sports grounds and recreation,
- Lawns and meadows,
- Land reclamation,
- Skiing slopes,
- Hobby gardens,
- Ornamental plant cultivation and tree nurseries,
- Surface layers on landfill sites,
- Methane oxidation layers,
- Biofilters,
- Compost as constituent in blends and substrates.

The recommendations for application are building the basis for placing tenders for landscaping and maintenance measures conforming to the standards.

The applications for horticulture, hobby gardening and skiing slopes fall within the field of agriculture regarding the basic requirements for compost quality (heavy metals, impurities) according to Compost Ordinance (BGBl. II Nr. 292/2001). The preparation of the application guidelines for agriculture together with the advisory board for soil fertility and soil protection is in the pipeline.

The recommended application rate in reclamation of skiing slopes is exemplarily described. Regarding the nutrient level three compost categories are distinguished.

TABLE 4-3: APPLICATION RATES RECLAMATION OF SKIING SLOPES

	Compost - nutrients (NPK)			**Incorporation depth**
	low	medium	high	
Light cohesive soils (sand); or a high portion of gravel	up to 15 l/m²	up to 10 l/m²	up to 5 l/m²	according to soil depth 0 cm – 10 cm
Medium to cohesive soils (silt, clay, loam to clay)	up to 20 l/m²	up to 15 l/m²	up to 10 l/m²	according to soil depth 0 cm – 5 cm

Required is here the utilisation of medium particle size (0 mm to 25 mm) mature compost (growth test with cress: plant fresh matter (PFM) ≥ 80 % at 25 % vol. compost ratio)

Application guidelines for compost from organic waste in agriculture (BMLFUW, 1999[FA752]):
This guideline of the advisory board for soil protection and soil fertility from the year 1999 was established even before the publication of the Federal Compost Ordinance. It is, however, in accordance with the Compost Ordinance regarding the maximum recommended application rates (8 Mg TM $ha^{-1}a^{-1}$). Reduced was the possible combining of yearly rates from 5 to 2 years giving a maximum amount of 16 Mg TM $ha^{-1}a^{1-}$ every two years. Regarding the approval limits for nitrogen loads of 175 respectively 210 Kg at an average N-content of 1.5 % d.m. a maximum application rate would be 11.7 or 14 Mg d.m. ha^{-1} respectively. A further judgement of nutrient supplies can be drawn from the *Guidelines of the good practice of fertilisation* (BMLFUW 2006c).

Further hints are given for compost maturity (fresh or mature compost), application rates and time of application in arable land, grass land, growing of field vegetables, viniculture, fruit cultivation and in organic agriculture.

Exemplary survey of the application recommendations in field vegetables, viniculture and fruit cultivation:

TABLE 4-4: APPLICATION RECOMMENDATIONS (AMOUNTS) OF THE APPLICATION GUIDELINES FOR COMPOST FROM ORGANIC WASTES IN AGRICULTURE

	Quantities	**Time, Tips**
Field vegetable cultivation		
low nutrient demand	5 Mg f.m. ha^{-1}	Mature compost
high nutrient demand	13 – 19 Mg f.m. ha^{-1}	
Means of crop rotation	11 – 14 Mg f.m. ha^{-1}	
Viniculture		
Humus substitute	15 Mg f.m. ha^{-1}	
Mulch to protect against erosion	10 – 30 mm	Coarse grained
substrate for planting	1/3 in soil mixture	Mature compost
Fruit production		
new cultivation	15 – 20 Mg f.m. ha^{-1}	Subsequent fertilising after 2–4 years
substrate for planting	20% in soil mixture	Mature compost
fruit trees and bushes	10 Mg f.m. ha^{-1}	Every 3 years

Guideline for the good practice of fertilisation (BMLFUW, 2006c): The latest edition of the guideline refers at some places to composts from organic waste.

- In order to calculate the chargeable nitrogen compared with the allowance limits for nitrogen according to the Water Act a N loss of 9% during application is acknowledged.
- The portion of NH_4-N in composts made from manure is assumed with < 1 %. The yearly effect of compost nitrogen is quoted with 10% of the nitrogen amount (= analysed value minus 9%) to be applied for arable and grassland. Further on a yearly follow-up effect of 3 to 5% of the applied compost-N has to be accounted.
- After regular long term application of manure and assuming favourable mineralisation conditions it is estimated that with the sum of the annual application and of all accumulated follow-up effects a 100 % N- efficiency of the nitrogen can be expected.
- A concrete recommendation for compost application is only available for grassland:
    - The application rate of compost (at assumed 50 - 60 % d.m.) should not be more than 15 Mg f.m. ha^{-1} per cutting or grazing period

- Grasslands rich in clover or other species cultivated extensively should obtain the low nitrogen demand over slowly flowing N-sources, i.e. should be preferably fertilised with stable manure or compost.
- Extensive meadows and clover dominated field fodder should be fertilised, if possible, with rotted manure or compost

4.3 *Provincial regulations on soil protection (Soil Protection Act, Sewage Sludge and Compost Ordinances of the provinces)*

Only such aspects are quoted here which relate to the application of compost in agriculture.

4.3.1 Upper Austria

<u>Upper Austria Soil Protection Act 1991 i.d.F. LGBl. Nr. 100/2005</u>

- Upper Austria follows the requirements for compost production laid down in the Compost Ordinance BGBl. II Nr. 292/2001 in all details.
- Basically, the application of compost quality classes A+ and A in agriculture is admissible without restrictions. Beyond the product regulations of the compost ordinance (irrespective of the restrictions for nitrogen fertilisation) the maximum rates to be applied within the waste regime follow the *Treatment Principles* of the *Federal Waste Management Plan*.
- During fertilising must be considered:
  - Properties of location, state of nutrient supply, nutrient demand, productivity, existing plant residues, nutrient enrichment from preceding crop (legumes), natural mineralisation processes, efficacy of fertilisers and development of vegetation (regarding the periodical spreading of fertiliser).
- By systematic supply of organic matter (stable manure, compost, crop residues, green fertiliser and similar) a proper humus management shall be achieved.
- Measures that are promoted (aim → maintenance, improvement or restoration of soil fertility and health) are:
  - Composting of organic waste
  - Measures for the improvement of the "quality" of sewage sludge or compost
- Consumers of compost are obliged to inform the competent authorities on
  - Purchase and application of compost,
  - Cultivation of the application sites
  - Mandatory records

  and have the obligation
  - to allow entrance to premises, application sites, storage areas for fertilisers
  - to allow sampling and analyses of soils

Upper Austria Soil Limit Value Ordinance 2006, LGBl. Nr. 50/2006

According to § 24 of the Upper Austria Soil Protection Act precautionary threshold values for soils are stipulated if exceeded, only composts of quality class A+ (according to the Austrian Compost Ordinance) are allowed to be applied without load limits for heavy metals. In the case of compost quality class A the heavy metal loads of the *Soil Limit Value Ordinance* must be observed.

4.3.2 Lower Austria

Lower Austria Soil Protection Act (NÖ BSG) Sheet 6160-0 58/88; LGBl. no. 25/05 from 2nd March 2005

- Compost is allowed to be applied on soils only if the compost has been produced according to the Austrian Compost Ordinance and the compost was used according to the application recommendations therein.
- Composts are only allowed to be applied under implementation of a quality assurance system stipulated by the plant operator as described in Annex 3 part 3 of the Austrian Compost Ordinance (this includes: documentation of source materials, processing and treatment, final product, applications)
- Obligation of information of compost producers
- Allowance of sample taking of soils by the competent authority where compost has been applied.
- Prohibition of compost application on sites where agricultural fertilising is restricted pursuant Nature Protecting Law (national parks, natural monuments with relation to an area, karst areas, moors, dry habitats and meadows)

Lower Austria Sewage Sludge Ordinance Sheet 6160-2 80/94; LGBl. no. 31/05; 31. March 2005

- No reference is made here regarding compost utilisation

4.3.3 Carinthia

Carinthian Sewage Sludge and Compost Ordinance – K-KKV; StF: LGB no. 74/2000; amended: LGBl no. 5/2004

- In the case of enduring production of food and feeding stuff an expert report about the application site must be provided prior to the first application of biowaste and green compost of quality class AB and B and further in an interval of 10 years.
- The soil expertise prior to application of compost of quality AB or B must not be older than 5 years

TABLE 4-5: HEAVY METAL CLASSES AND MAXIMUM APPLICATION RATES FOR SEWAGE SLUDGE AND COMPOSTS OF THE KÄRNTNER SEWAGE SLUDGE AND COMPOST ORDINANCE

	Heavy metal classes [mg Kg^{-1}d.m.]			
	B	**AB**	**A**	**I***
Cd	2,5	2	1	0,7
Cr	100	70	70	70
Hg	2,5	2	0,7	0,4
Ni	80	60	60	25
Pb	150	150	150	45
Cu	300	300	150	70
Zn	1800	1200	500	200
Maximum application rates [Mg d.m. $ha^{-1}2a^{-1}$]				
	6	10	16	>16

* minimum quality for organic agriculture

TABLE 4-6: LOAD LIMITS FOR HEAVY METALS, WHICH ARE ALLOWED TO BE APPLIED ON THE SOIL PER HA AND YEAR OVER A PERIOD OF 10 YEARS:

Cd	**Cr**	**Hg**	**Ni**	**Pb**	**Cu**	**Zn**
g $ha^{-1}a^{-1}$ (on a 10-years average)						
6	350	6	300	600	1800	4500

4.3.4 Burgenland

Bgld. Soil Protection Act, LGBl. no. 87/1990; amended: LGBl. no. 32/2001

- No definite regulations for the application of organic waste compost exist

4.3.5 Salzburg

Salzburger Sewage Sludge and Soil Protection Ordinance, StF no. 85/2002

- General prohibition of the use of sewage sludge which has not been composted
- Definition of *sewage sludge compost* and *quality sewage sludge compost* according to the Austrian Compost Ordinance
- Comprehensive rules for the restricted use of *sewage sludge compost* and *quality sewage sludge compost* including the required documentation:
  - o Soils must not serve:
    - *a) Directly for the production of foodstuff (e.g. arable land for cereals, potatoes, vegetables, berry fruit and medical herbs);*
    - *b) Indirect for the production of foodstuff (e.g. arable land for animal feeding, permanent grassland, alternate grassland, pasture land).*
  - o Such utilisation of soils is also prohibited in the 4 years following the application of quality sewage sludge compost.

4.3.6 Tyrol

Tyrolean Land Protection Act 2000; amended; LGBl. mo. 56/2002

- The Tyrolean Land Protection Act contains a general prohibition for the application of sewage sludge and compost from sewage sludge on agricultural areas
- No definite regulations for the application of organic waste compost

4.3.7 Styria

Styrian Agricultural Soil Protection Act; LGBl. no. 66/1987
amended: (1) LGBl. no. 58/2000; (2) LGBl. no. 8/2004

Sewage Sludge Ordinance; LGBl. no. 89/1987;
amended: (1) LGBl. nor. 11/1988; (2) LGBl. no. 51/2000; (3) LGBl. no. 73/2003

- Exclusively out-dated regulations for „mixed waste compost“ which do not correspond any more to the requirements of the Federal Compost Ordinance

4.3.8 Vorarlberg

Sewage Sludge Act; LGBl. no. 41/1985, 57/1997, 58/2001

Sewage Sludge Ordinance; LGBl. no. 75/1997, 27/2002

- The law exclusively regulates the application of sewage sludge and products therefrom (*„...sewage sludge, indifferent of consistency whatsoever”)*
- Composted sewage sludge is summarised together with thermally dried sewage sludge as *sewage sludge fertiliser*. These are the only forms for which sewage sludge is allowed to be delivered for application on land.
- The quality requirements and conditions for application are not in line with the requirements for production and marketing of compost of quality class B of the Austrian Compost Ordinance and the Federal Waste Management Plan.
- Application restriction is rerlated to a maximum phosphorous load per hectare (usually max. 160 Kg P_2O_5 $ha^{-1}a^{-1}$)

4.3.9 Vienna

Act on the prohibition of applying sewage sludge; LGBl. no. 08/2000

- General prohibition for the application of sewage sludge, except of hygienically approved products containing treated sewage sludge and if marketing, especially as fertiliser, compost and manufactured soils is allowed according to federal legislation

4.4 European provisions

4.4.1 Animal By-Products Regulation (EC) n° 1774/2002

Organic fertilisers and soil improvers other than manure pursuant to Regulation **(EC) Nr. 181/2006**[FA753] **from 1. April 2006**

Art 22 (c) of the Regulation (EC) Nr. 1774/2002 prohibits

> *„the application to pasture land of organic fertilisers and soil improvers other than manure. “*

Whereby pasture land is defined as follows:

> *“pasture land” means land covered with grass or other herbage grazed by or used as feedingstuffs for farmed animals, excluding land to which organic fertilisers and soil improvers have been applied in accordance with Commission Regulation (EC) No 181/2006”*

There is basically no restriction for the application of compost which was produced of category 3 catering waste or manure respectively

From April 1st, 2006 the following regulations are valid for composts and digestion residues produced from **all other category 2 and 3materials**:

- Records shall be kept for at last two years on
  - quantities of organic fertilisers and soil improvers applied;
  - the date on which and the places where organic fertilisers and soil improvers were applied to land;
  - the dates on which livestock is allowed to graze the land or on which the land is cropped for feedingstuffs.

- Special grazing restrictions – 21 days waiting period between application and harvest of forage grass or grazing

  ” Where over 21 days have elapsed since the date of last application of organic fertilisers and soil improvers, grazing may be allowed or the grass or other herbage may be cut for use in feedingstuffs, provided the competent authority does not consider that the practice presents a risk to animal or public health.”

  The commercial document accompanying organic fertilisers and soil improvers shall bear the words *‘organic fertilisers and soil improvers/farmed animals must not be allowed access to the land for at least 21 days following application to land’*.

4.4.2 Elements of the EC draft amendment of the Waste Framework Directive[4]

4.4.2.1 Definition of recycling and recovery methods

The *definition* of „recycling“ is stipulated in article 3:

> *"'recycling' means the recovery of waste into products, materials or substances whether for the original or other purposes. It does not include energy recovery"*

In order to provide a clear differentiation between recovery and disposal it would be of significant meaning to put distinct emphasis on *material recycling*.

As described in the previous chapter it is of key importance to draw a distinct qualitative borderline between recycling and disposal for the various waste types and treatment processes.

This makes it necessary to record more specific *quality criteria* in the existing *European Waste Catalogue* in order to define their suitability for certain recycling methods.

4.4.2.2 End of waste regulation

The Commission provides a strategic proposal for elaborating *End of Waste Regulations* in the *Strategy on the Prevention and Recycling of Wastes.* A pilot scheme in envisaged for *compost*.

The general requirements for this task are laid down in article 11 "secondary products, materials and substances". As pre-conditions (which will be checked by the commission) whether it is appropriate to deem certain waste to have ceased being waste it is listed:

- no overall negative environmental impacts;
- the existence of a market
- Are both criteria fulfilled the commission enacts measures to be carried out following a comitology process defining environmental and quality criteria to be met in order for that waste to be deemed to have become a secondary product material or substance
- Hereby is assured,
    - the equivalency with primary products or primary materials
    - the fulfilment of the necessary conditions to be placed on the markez
- All risks of an environmentally harmful utilisation or application must be considered
- A high level of protection of human health and environment must be guaranteed

4.4.2.3 Exemptions of the scope

It is interesting that it is suggested that – in contrast to all other animal by products which are ruled under the ABP Regulation *(EC) Nr. 1774/2002* – composting and digestion of organic wastes from households and central kitchens (catering waste) which could contain animal by-products are kept under the scope of the draft directive (Article 2):

> *"It shall not cover animal carcases or animal by-products intended for uses in accordance with Regulation (EC) No 1774/2002 without prejudice to the application of the present Directive to the treatment of biowaste that contains animal by-products."*

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[4] http://ec.europa.eu/environment/waste/strategy.htm
http://eur-lex.europa.eu/LexUriServ/site/en/com/2005/com2005_0667en01.pdf

That means that in future biowaste, especially from kitchen and food wastes and probably also certain fractions of *former foodstuff,* are subject to the regulation of the Waste Framework Directive. This principle has been stipulated already in the Animal By-Product Regulation (EC) Nr. 1774/2002

4.4.3 The Thematic Strategy on Waste Prevention and Recycling (COM(2005) 666)[5]

At present approximately 33% of municipal wastes are recycled or composted. The biowaste potential from separate collection in the EU is about 80 – 100 million Mg (wit the inclusion of industrial waste approx. 150 million Mg). About 25% of this amount is processed in compost or biogas plants.

The strategy is above all to increase recycling. By the diversion of biodegradable household waste from landfills to composting, recycling and energy recovery an additional mitigation of greenhouse gas emissions of 40 to > 100 Mt CO_2 equivalent per year can be expected.

As waste moves away from landfill it will be channelled into a variety of options higher up the waste hierarchy, all of which will be better for the environment. The report about the individual strategies of the Member States to achieve the diversion targets for biodegradable waste from landfills says:

> *However, the Commission's report on the national strategies concluded that "having analysed the strategies it is unclear whether the landfill reduction targets will be achieved for those Member States where this is not already the case. It looks like additional efforts will be necessary to achieve the targets. The Commission will pay particular attention to the attainment of the target of 2006 and take all appropriate measures to ensure good implementation of the directive"*

This is not very promising. The Commission's believe is that *the development of quality benchmarks for composting facilities and for compost will increase the prospects for composting.*

It is emphasised that these processes of composting and energetic recovery are currently used to a poor extent in some member states.

It is stated that there would be *no single environmentally best option for the management of biowaste that is diverted from landfills. The environmental balance of the various options available for management of this waste would depend on a number of local factors, inter alia*

- *collection systems,*
- *waste composition and quality,*
- *climatic conditions,*
- *impact on climate change,*
- *the potential of compost to contribute to fighting soil degradation and*
- *other categories of environmental impact.*

Therefore strategies for management of this waste should be determined by the Member States using life-cycle thinking.

The commission intends to prepare corresponding guidelines for the application of life cycle analysis in biowaste management and to ask the member states to check their national strategies on behalf of this.

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[5] http://eur-lex.europa.eu/LexUriServ/site/en/com/2005/com2005_0666en01.pdf

Further, *compost quality criteria* will be adopted under the *end-of-waste provision* proposed for the Waste Framework Directive

In preparation of a end of waste provision the commission has launched a project with the Joint Research Centre in Seville in order to evaluate the conditions under which defined waste materials that have undergone a composting process may cease to be a waste and consequently could be certified as a *compost product* (e.g. process requirements as well as compost quality and labelling criteria). This study is due for publication in autumn 2008 and would constitute the technical basis for a legal provision to be adopted under the comitology procedure.

A binding provision which would encourage the establishment of separate collection systems for organic wastes cannot be found in the draft of the Waste Framework Directive nor in the strategy paper!

The Commission proposes that biological treatment of waste to be brought under the scope of the IPPC Directive. This would need the definition of BAT (*best available technique*) documents.

As the so-called BAT documents of the IPPC Dir. are designed for large-scale plants with probably considerable impacts on the environment it is questionable to list Europe-wide requirements for compost plants which exclusively process biowastes. Possible effects on the environment are to be seen in odour emissions for which the location and the treated amount of waste should be stipulated within the permits procedure covering requirements for exhaust air treatment, process management, etc.. This can preferably be realised by flexible national standards which take into account individual, local conditions. Furthermore it must be distinguished between large-scale plants and small facilities (e.g. below 5000 Mg treated material per year) – the standard case in biowaste and garden waste composting.

It is to be feared that a European Regulation will establish unreasonably high requirements on technical standards (housing, enclosed processes with exhaust air treatment) even for small and medium-sized plants. This would endanger ecologically and economically effective and approved systems of biowaste composting in many member states and would avoid flexible small-sized structures which respect the prominently demanded principle of proximity.

Regarding an end of waste- regulation it reads:

> *"This means that it is possible to select those waste streams for which criteria need to be set on the basis of potential environmental and economic benefit. The first wave of waste flows to be addressed by this system will include compost, …"*

A two-step approach is chosen:

1. *establish in the Waste Framework Directive the procedure for adoption of the criteria*
2. *propose specific waste streams for this system, selected on the basis of environmental and economic benefit.*

Council Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture will be revised with a view to tightening the quality standards under which such use is allowed following the adoption of the Thematic Strategy on soil and the associated measures.

The Commission will review the progress made towards achieving the strategy's objective in 2010. This review will, in particular, assess progress on waste prevention policies, on applying life-cycle thinking to waste management – *including management of biowaste* – and towards a European recycling society and will feed into the final evaluation of the Sixth EAP. *The review of the strategy will, in particular, address the progress made on management of biowaste and assess the need for additional measures.*

4.4.4 The thematic strategy on soil protection

During the first phase of the EU Soil Protection Strategy the consultation paper of the Commission[6] included the following keywords (shortened):

- From 2002 onwards, the Commission will propose a series of environmental measures designed to prevent soil contamination, including legislation related to …. sewage sludge and compost ….. A progress report will be prepared in mid 2004.
- The build-up of organic matter in soils is a slow process (much slower than the decline in organic matter). This process is enhanced by positive farm management techniques such as …. mulching, manuring with …. compost, …. Most of these techniques have also proven effective in preventing erosion, increasing fertility and enhancing soil biodiversity.
- By the end of 2004 a directive on compost and other biowaste will be prepared with the aim to control potential contamination and to encourage the use of certified compost.
- The Common Agricultural Policy already provides opportunities for soil protection. A number of agri-environmental measures offer opportunities for the build-up of soil organic matter, the enhancement of soil biodiversity, the reduction of erosion, diffuse contamination and soil compaction. These measures include support to organic farming, …, and the use of certified compost.

The reactions of the EU Institutions have been positive and motivating. Here some relevant elements from different documents:

Council meeting - Luxembourg, 25 June 2002 – Soil Protection Council conclusions

- (…) STRESSES that ongoing environmental legislation initiatives on compost, (…) and sewage sludge, (…) will make an important contribution to soil protection and REQUESTS the Commission to present the appropriate proposals as soon as possible;

Decision of the European Parliament and the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme

- –Article 8 - Objectives and priority areas for action on the sustainable use and management of natural resources and wastes (…) shall be pursued (…) by means of the following priority actions: (iv) Developing or revising the legislation on wastes, including, inter alia (…) sewage sludge (2), biodegradable wastes,(…)

European Parliament Report on the Commission communication 'Towards a Thematic Strategy for Soil Protection'

- –pt 17. Urges the Commission to draw up a directive on compost; stresses the need to intensify research in this field so as to boost its potential for the recovery of soil lacking in organic matter and bring together waste management and soil protection and enrichment;

European Parliament resolution on the communication from the Commission: Towards a thematic strategy on the prevention and recycling of waste

- –27. Welcomes (…) the Commission's plan to submit proposals during 2004 on biodegradable waste;

Consultation regarding the EU Soil Protection Strategy

In February 2003 a wide range of experts and representatives from member states have been invited to a *stakeholder meeting* for the technical planning of concrete proposals for politicy and research for the realisation of the strategy with regulative measures, 5 working groups and an *Advisory Forum* have been founded.

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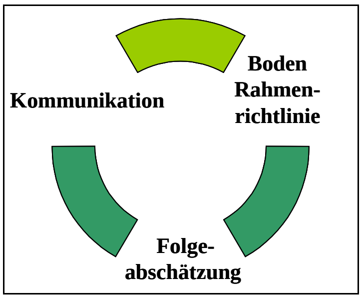
[6] KOM(2002) 179 finally, information of the Commission to the Council, the European Parliament, Economic and Social Council and the Council of the regions. "Towards a specific soil protection strategy" Brüssel, den 16.4.2002

FIGURE 4-1: THE REPORTS OF THE EXPERT GROUP FOR THE EU SOIL STRATEGY

In their final reports the 5 working groups (Organic Matter, Erosion, Contamination, Monitoring, Research) delivered recommendations for the areas of Policy, Research and Monitoring. The results including all technical annexes are available on: http://forum.europa.eu.int/Public/irc/env/soil/library. The final reports can be downloaded under http://eusoils.jrc.it/ESDB_Archive/Policies/STSWeb/start.htm or ordered as a brochure at env-soil@cec.eu.int

Figure 4-2: The „soil package“ includes: the Soil Framework Directive, a Communication and an Impact Assessment



The recommendations of the working groups for compost utilisation can be summarised as follows:

- The application of EOM on soil is in principle recommended if it is of an appropriate quality and if it is applied according to good practices.
- If these two requisites are fulfilled, the application of EOM is recommended because it can contribute to maintaining adequate soil organic matter levels and to managing soil organic matter and assist with
  - reducing soil erosion
  - enhance soil bio-diversity and biological activity in soil
  - better aggregation
  - better porosity of soils.
  - improve tilth and workability,
  - increasing buffer capacity,
  - reducing nutrient leaching,
  - improving water retention,
  - saving of resources and energy (e.g. mineral fertilisers, pesticides, traction power for soil cultivation)
  - diverting carbon dioxide from the atmosphere and converting it to organic carbon in soils, contributing to combating greenhouse gas effect.
- For a precautionary and sustainable protection of the soil the following has been claimed:
  - A positive list of high quality source materials for composting and anaerobic digestion intended for the processing of organic soil amendments would be essential to guarantee high quality compost. This should include source separated household waste and green waste as well as organic industrial waste (e.g. from food industries).

- In order to bridge the gap between targets for the reduction of biodegradable municipal waste to landfill and a sustainable use of the biodegradable waste fraction incentives for the recycling of source separated biowaste are essential. Member States are encouraged to explore the best solution for implementation considering local conditions.
- Stabilised MBT material shall remain under the waste regime and shall be restricted to limited applications (e.g. as cover for landfills)
- Europe-wide minimum quality standards for marketable composts
- Medium-termed harmonisation of precautionary requirements for all types of soil improvers and fertilisers, inclusive animal manure (e.g. potential contribution to soil contamination)

The draft Soil Framework Directive has been published in September 2006 and is currently under consultation within the EU institutions and stakeholders. The Directive does not deal with diffuse inputs like from the utilisation of organic waste or sewage sludge. In the case of the potential threats erosion, organic matter decline, compaction, salinisation and landslides Member States shall identify risk areas according to stipulated criteria and work out corresponding sanitising strategies and measures. Besides the Directive the soil package includes a communication the general outline of soil strategy and a document with a comprehensive assessment with regard of socio-economic and environmental impacts of the Directive.

In conclusion it has been recognised that the recycling of composted organic waste, in particular alongside the implementation of a quality assurance system, is an important contribution to maintain soil fertility.

But still there is no consistent strategy to be found in one of the currently discussed Directives on waste or on soil respectively which would handle the organic waste stream in an adequate way to the benefit of the soil and the environment.

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List of abbreviations

Composts / fertilisers		Crops	
BWC	Biowaste compost	Bar	Barley
CM	Cattle manure	Ca	Cabbage
Comp	Compost	Corn-M	Corn maize
DBM	Deep bedding manure	FE	Forage peas
FM	Fresh manure	For-M	Forage maize
gr.BWC	Granulated biowaste compost	FB	Fodder beet
GWC	Green waste compost	IC	Intercrops
LM_U	Liquid manure (Urine)	Ley	Ley
LU	Life stock unit	M	Maize
MC	Manure compost	O	Oats
MC_C	Cattle manure compost	OR	Oil radish
MC_H	Horse manure compost	Pot	Potatoes
MC_P	Pig manure compost	Pu	Pumpkin
min.	Mineral fertiliser (e.g. NPK)	Tom	Tomatoes
MWC	Mixed waste compost	R	Rye
MWSC	Mixed waste/sludge compost	W	Wheat
NPK	NPK fertiliser	Ra	Rape
P-K	PK fertiliser	BR	Beetroot
RotM	Half rotted manure	SB	Sugar beet
Slu	Slurry	S-Bar	Spring barley
SMC	Spent mushroom compost	S-R	Spring rye
SSC	Sewage sludge compost	SF	Sunflowers
St	Straw	Sil-M	Silage maize
StabM	Stable manure	Soy	Soy bean
StMu	Straw mulch	Sp	Spelt
StoM	Stocked manure	SC	Sweet corn
		W-Bar	Winter barley
		W-R	Winter rye
		W-W	Winter wheat
Others			
CR	Crop rotation	OPs	Organic pollutants
DOC	Disolvable organic carbon	PKa	acid dissociation constant
d.m.	Dry matter	POPs	Persistant organic pollutants
f.m.	Fresh matter	PTE	Potential toxic element
GAP	Good agricultural practice	SOM	Soil organic matter
HM	Heavy metals	WOS	Water soluble organic matter

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