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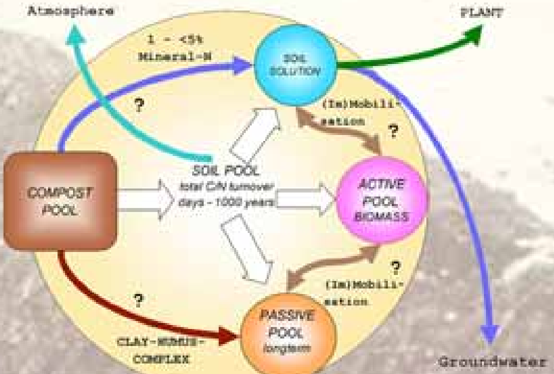
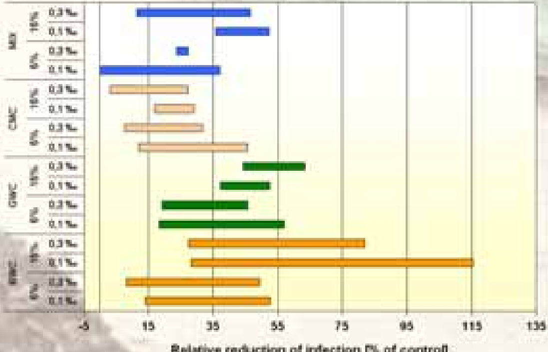
APPLYING COMPOST BENEFITS AND NEEDS





Seminar Proceedings
Brussels, 22 – 23 November 2001

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APPLYING COMPOST BENEFITS AND NEEDS

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Brussels, 22 – 23 November 2001

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PREFACE

During the first decade of source separation and biowaste composting predominantly the discussion on compost use focussed on potential pollution issues. Questions of ecologically beneficial effects of compost where somehow disregarded. In view of the future adoption of a Biowaste Directive and continuously increasing figures for biowaste and green waste compost generation, the Austrian Ministry for Agriculture & Forestry, Environment & Water Management initiated a literature research on the "*Evaluation of Sustainable Beneficial Effects of Compost on Soil Fertility and Soil Productivity*".

In order to discuss the results of this research with experts at the European level, the Environment Directorate-General of the European Commission and the Ministry for Agriculture & Forestry, Environment & Water Management of the Republic of Austria organised a scientific seminar on "*Applying Compost – Benefits and Needs*" in Brussels on 22 and 23 November 2001.

The seminar, with invited international experts, intended to share the outcome of the literature research with the results of the latest findings by scientific research work. Furthermore, the hypothesis was to discuss with colleagues not only from the scientific world (plant production, soil science etc) but also with experts from agricultural organisations and official bodies and authorities on national and EU level of the concerned areas (soil protection, water conservation, agriculture).

Compost additions to soil have the potential to contribute in the following areas:

- Improve soil physical conditions increasing resistance to erosion, improving soil workability and water infiltration and water holding properties.
- Improve soil fertility
- Increase soil biodiversity
- Sequester carbon in the soil.

The need to maintain and improve these properties have been recently highlighted by the Commission itself in its Communication "Towards a Thematic Strategy for Soil Protection" (COM (2002) 179 final).

More than 100 representatives from academia, regulators, agricultural organisations and compost management attended the seminar to discuss the experience of beneficial effects of compost to the soil-plant-system.

The presentations as well as the plenary contributions supported the outcome of the literature review – that is compost induces positive effects by offsetting organic carbon losses and improving key soil fertility parameters.

We hope that these proceedings may serve as a further contribution to best practice when compost is used in agriculture to the benefit of a sustainable organic matter management of European soils.

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CONTENTS

EXECUTIVE SUMMARY

HIGHLIGHTING KEY OUTCOMES FROM PRESENTED PAPERS AND THE DISCUSSION

For this summary it was not intended to refer all statements having been put forward during the seminar. Still the mayor outcomes of the session's discussion as related to the paper presented are summarised. All references made here are quoting the papers of these proceedings.

Session 1: N and C pools – what is their Fate in Compost Amended Systems?

The soil carbon pool

Throughout compost application trials a constant increase in soil organic matter (SOM) is reported. The main factors influencing this increase in SOM are the amount and type of material applied, the maturity of compost and the soil properties. More mature compost leads to a higher grade of SOM increase in the soil. But also the type and amount of crop residues play an important role in the SOM maintenance or build-up respectively in long term experiments. C-mineralisation of amended (mature) compost under laboratory conditions is low (1 to 20 % of applied C_{org}).

In long term trials this was also related to increased soil microbial activity (DOC trial Switzerland; *see Mäder*). As for carbon sequestration when added to soil compost has to be quoted as viable mid term organic carbon sink.

There was a degree of inconsistency in the results presented on SOM accumulation versus the range of sources available. It was considered that over a 30 year period, carbon-source was unimportant, with no significant differences being noted from a range of materials such as straw, compost or manure. However the 21 year DOC trial gives clear indications for a more sustainable SOM built-up in plots fertilised with composted manure as compared to stable manure. The evaluation of long term field trials gave an overall potential for decomposable C_{org} variation via organic amendments (stable manure) of only 0.2 to 0.6 % (*see Körschens*). This predominantly depends on clay content. Humification rate in clay soils is considered to be twice of what is observed in sandy soils. Nevertheless SOM diversity and stability are still insufficiently known.

In this respect the question "why do we apply carbon?" has to be raised (and answered) for short or for long-term benefits. In particular changes over time require further study.

Assuming a minimum level of 1.1 to 1.5 % organic carbon in the soil the need of compost as supplementary organic amendment was identified in a national survey in France. (*see Le Villo et al.*).

A regulatory framework should not be unidimensional and too prescriptive and should take account of the needs of both short-term use (enhancing microbial transformation processes) and long-term strategic planning (build up and maintain a sustaining organic carbon pool as soil amelioration measure). Local conditions should be taken in consideration (soil properties, climate, crop and soil management, system and level of fertilisation). Compost is a very varied material depending on feedstock and composting process. This has to be taken into account for proper application.

Finally the need for standardised analytical methodologies for organic carbon and the interpretation thereof was identified.

Nitrogen dynamics and leaching

Accordingly to organic carbon degradation, incubation tests have shown N mineralisation rates of 0 – 30 % of total compost N. Immobilisation is supported by less mature (fresh) compost and high C / N ratio (ca. > 18). Under field conditions not more than 10 to 15 % of the total nitrogen applied with compost is plant available in the year of application. However subsequent compost additions may raise this figure up to 45 % in the course of several crop rotations.

This low mineralisation level is also indicated by only small differences in nitrate concentrations in the leaching layer of compost amended soils or in the water leaching to groundwater respectively, when compared with mineral fertilised or control plots without fertilisation. Depending on precipitation rates and quantity of compost applied (N supply up to the 9-fold of mineral fertilised plots) lysimeter trials show similar N-leaching rates as compared to mineral fertilisation. In combined compost / mineral N fertilisation plots during one year after compost application (at 360 kg N equivalent) N leaching was increased by 20 kg ha^{-1}. It is also shown that compost may replace mineral N fertiliser (52 to 143 kg ha^{-1}y^{-1}) in an intensive maize production system when combined with slurry fertilisation (*see Nevens*).

From the presented papers it was suggested to consider N mineralisation dynamics in terms of the material specific organic sorption of nitrogen for regulation of N-containing fertiliser. Another way would be to calculate maximum N loads via composts on a three year budget rather than on a year by year basis. Furthermore it was addressed that a potential unstable situation over a 20-30 year period may occur. This could result in climate-induced peaks and troughs of nutrient availability.

It was demonstrated that interactions through crop rotations (including green manure and intercropping) must nonetheless be considered over time when aiming at an optimised compost N utilisation.

Session 2: Plant Nutrition and Productivity - is Compost a Competitive Fertiliser?

It was also raised to what extend compost is a provider of other plant nutrients as well as creating a good plant growing environment within an integrated soil fertility system.

After continued compost application total and available ***phosphorus*** and ***potassium*** concentration respectively in the soil are increased. In contrast to nitrogen P, K and Mg show in principle higher plant availability. Though plant availability of P in the first years is still lower than for mineral P fertiliser. However figures gained from field experiments also vary within a wide range depending on soil as well as compost properties (20 – 70 %). Other experiments demonstrate an additional plant uptake lower than 10 % of the P and K supply via compost whereas the available proportion of P and K in the soil increased significantly. It was suggested that for both, P and K the total load applied with compost should be considered in the nutrient balance of the fertiliser regime.

For ***sulphur*** low short term availability (5 – 10 % of total sulfur load) was reported. Long-term compost amendments resulted in increased S mineralisation and thus lower mineral S demands.

Summarising the presented papers and literature data on a short term scale compost does not perform as a sufficient nitrogen source for actual plant nutrition at moderate rates of application. This again has to be related to the site specific mineralisation potential and seasonal variations.

It was mentioned that on field scale compost may, from time to time, represent an over-supply of nutrients (e.g. for phosphorus and potassium). However, on a national scale, approximately 1-2% of nutrients are likely to come from compost and these will therefore represent only niche products in some markets.

In a Swiss questionnaire with farmers approximately 50% considered the addition of organic matter as the predominant value, while others valued the phosphorus, potassium and magnesium contribution. The nitrogen value of the material was generally regarded as less significant and this would tend to indicate the need for a balanced contribution of compost, plus plant nutrients from other sources, either mineral fertilisers or organic products.

Addressing parameters other than the major plant nutrients, though differences with or without the application of compost to vegetable plots may be observed, plant vitamin and mineral content differ substantially between cultivars, and this may be more significant than the choices between individual compost types (*see Warman*).

Yield is very much influenced by differences between (i) quantity and frequency of compost application, (ii) crop-rotational schedules, (iii) site specific yield potential and (iv) supplementary mineral N fertilisation. Many vegetables such as cabbage, lettuce, onions, cucumber show positive responses on compost amendments. Crops with long growing period show a better response. As compared to control plots (no fertilisation) compost provides enhanced yields. In several compost trials combined compost and mineral N fertilisation performed best whereas in the first years of compost amendment with higher quantities every 2 to 3 years led to advantages against yearly applications at low rates. It may be concluded that due to low N efficiency a positive yield effect of compost is achieved in the long term on soils, which are continuously managed with compost rather than after one or two applications.

It was agreed that compost cannot be considered only in mineral terms. This is because compost contributes to the availability of nutrients within the soil matrix, not just supplying minerals in the way that conventional fertilisers do. The “systems-approach” to compost development needs to be considered.

Session 3: Compost Impacts on Soil Biology and Antiphytopathogenic Potential

Soil biology

Indicators for the transformation function of soils such as specific respiration, microbial biomass C and several enzyme activities have been investigated frequently in compost trials. Significant positive effects of compost amendments have been found for the majority of these parameters. This has also been proved in long term trials, e.g. for composted cattle manure, which showed highest results of soil microbial biomass as compared to mineral fertiliser and fresh manure systems after 3 crop rotations (21 years; *see Mäder*). From a comparative laboratory trial with 3 different test methods it was shown that the composition of the micro flora rather than microbial abundance was distinctly influenced in its genetic composition as well as in their ability to use different carbon sources (*see Postma & Kok*).

In addition investigations on soil fauna (e.g. earth worms, collembola) and feed activity show enhanced abundances and activity in compost plots as compared to control plots with and without mineral fertiliser.

Suppressive effects against soil born plant diseases

Suppressive effects of compost as growing media constituent against soil born plant diseases has been reported since the early 60's. Though single key factors which cause this effect systematically could not be identified. Anyhow the presence of specific antiphytopathogenic micro organisms or consortia is a pre-condition.

Especially well matured compost in horticulture demonstrated high supressiveness against *Pythium ultimum* and *Rhizochtonia solani*.

It was confirmed that age of compost may be relevant, but that this is not yet absolutely defined. It was noted that the literature tends not to report negative effects. It was also mentioned that some treatments can enhance disease and that timing of compost production and compost use is an important factor. That some composts have suppressive activity and others do not was generally considered to be significant and that further work is required to determine recommendations for the definition of compost quality use. An example of suppressive composts potentially improving potato skin finish was given. Also a reduction of infection with cereal mildew was observed in compost amended plots as compared to mineral fertilised plots (*see Hartl et al.*).

The systems approach has to be the way forward, covering not only nutrient value and physical properties, but also disease suppression for primary pathogens and also those affecting crop quality.

Session 4: Aspects of Soil Protection – Against Potential Pollutants

This session dealt particularly with the sorption and fixation capability of composts for inorganic and organic pollutants, and with the impact of composts on the decay of organic compounds.

The dynamics of potential pollutants are influenced by site-specific properties and by the nature of the compost. In any one situation, a particular soil system may act as a source or a sink for potential pollutants. There is a positive correlation between SOM and total concentration of ***heavy metals*** in managed soils but a negative one between SOM and availability of heavy metals.

E.g. for Cd and Zn in several field trials compost application lead to a decrease of the extractable fraction and to a lower uptake by plants. This was explained by enhanced adsorption capacity (surface activity) introduced with compost (*see Petruzzeli & Pezzarossa).* An important pre-condition is the use of 'clean' compost in order to provide sufficient unoccupied absorption sites. It was also shown that in the course of compost maturation the solubility of heavy metals (predominantly Cu and Zn) declines.

When looking at the overall perspective of heavy metals in composts, only the soluble forms are relevant in respect of any environmental interactions. In terms of release and, most significantly availability, pH is the over-riding factor.

It was emphasised that in this sense compost additions are uniformly beneficial, particularly in contaminated soils.

An extensive discussion on the need for threshold values either for *'total'* or for *'extractable'* heavy metals led to the following contributions:

The use of compost in agriculture, compared to the use in land remediation is two totally different subjects. Total heavy metal levels are very important since the change of use and uptake by soil flora will relate to totals, whether bound or available. In contrast the risk of analysis based simply on totals was emphasised because when looking only at totals this does not distinguish between non-compost sources and specific solubility properties of compost. Besides standardised analytical methodologies as the basis for a unique interpretation, interactions between heavy metals should also be taken into account to predict availability. A simplistic approach to assessing total heavy metal content of composts and target soils does not achieve this. But at present no commonly agreed methodology is available.

Further the determination of risk management of heavy metals was encouraged, not just precautionary regulation. This requires further understanding of interactions such as metal – metal balances, or pH management. The key is the understanding of soil functionality in the frame of the particular land use and the possible changes in time caused by management and other external impacts (e.g. acidification, atmospheric deposition). However regulations governing the use of composts have to include a certain flexibility. Thus European wide or even national unique threshold values should acknowledge the variability associated with soil type and environmental context. 'High' or ‚low' quality compost may have an entirely different meaning on different soils and uses.

It was noted that proper management of compost can be used to create soils for regulated use in non-crop environments. Particular examples would be the use of compost-amended road verges. This should be encouraged by the public sector throughout the EU.

Uniform or at least comparable methods of risk assessment which include the specific benefits (Plant nutrients, organic matter, enhancing soil physical properties etc.) for the use of all types of fertiliser would be reasonable.

In any case since proper source separation and material management has provided a significant increase of quality the production of poor quality compost should belong to the past.

For ***organic pollutants***, such as pesticide residues, there is no strong evidence that there are any particular problems of accumulation in compost as long as it originates from source separation systems. However, organo-chlorine pesticides could potentially accumulate but most modern organo-chlorine pesticides are generally degraded to very low concentrations during any optimally managed composting process. In any event, such materials are generally not now permitted. Compost application also is likely to reduce the potential leaching of pesticide residues from soils.

The paper of *Houot* concludes that mineralisation of pollutants (PAH and PCB) was particularly noted from mature compost. On the other hand immature compost can create unextractable micro-pollutants in the soil environment, but mature compost only is capable of true degradation. Control of maturation and compost quality is therefore an important technical and regulatory objective.

It was discussed in considering more complex micro-pollutants that fixation of unextractable residues can be enhanced at very high microbial activities.

Session 5: Ameliorating Physical Properties – how Effective is Compost?

In this session key papers covered the long-term effects of compost application on run-off soil erosion and physical properties after a number of years. The application of compost shows mostly positive effects on aggregate stability and other physical properties (e.g. pore volume, bulk density, water capacity, hydraulic conductivity infiltration rate etc.; see also *Kluge and Bolduan*). It appears that aggregates > 20 µm are more affected than micro-aggregates. This corresponds with the predominant increase of coarse pores (> 50 µm) in loamy soils both in short term (3 years) and in long term (22 years) compost plots (see *Ebertseder and Gutser*)

In erosion trials soil losses and total run off of compost treated plots were significantly reduced accompanied by a decrease of bulk density and an increase of organic carbon and hydraulic conductivity respectively (see *Strauss*). Infiltration and erosion rates are dynamic processes and that properties change at differential rates. Erosion rate will most likely change over a longer period than infiltration rate.

Co-utilisation with other materials such as shale and rock dust was presented as examples of soil-(aggregate) forming capabilities of compost. These potential "soil" manufacturing processes are not possible with mineral fertilisers or other materials on their own. Following this it was recommended that composting should be managed to upgrade the fertiliser value of materials, and therefore the commercial value.

In relation to soil physical properties we need a better understanding of the influence of different carbon sources and for this information to be part of the planning of compost additions in the broad area of soil improvement..

It was stated that not the single parameters but the sum of observed benefits have to be considered as the main effects of compost additions. This led to the conclusion that especially in long term compost management compost may be seen as a soil improver rather than an immediate supplier of plant nutrients, gradually enhancing soil fertility parameters and therefore stabilising productivity.

General Conclusions

As a general conclusion the following contributions may be highlighted

- Different objectives have to be considered:

  short-term use of compost, targeting supply of nutrients and enhanced microbial activity or *longer term benefits* which tend to maximise the build-up of C-pools, nutrient pools and improvement in soil physical properties.
- The beneficial effect of compost on soil quality by maintaining and enhancing the SOM pool was supported by the results of several speakers, but the relationship

between soil type, compost type, application rate and time, including seasonality remains still not fully understood.

- On national scale high quality compost from organic waste can be an important source for maintaining a minimum required organic carbon content in the soils.
- Composting and compost use contributes positively to global carbon budgets
- Low nitrogen availability of compost is an agreed fact that in the medium term scale can be of advantage in water conservation programmes together with appropriate land management.
- At least in the course of crop rotations compost derived phosphorus and potassium may be recognised as fully available in the nutrient balance of fertiliser plans.
- Compost additions can add to an enhanced fixation and sorption capacity for potential inorganic and organic pollutants as well as enhancing the degradation of organic contaminants during composting and in the soil.
- Only clean, high quality compost guarantees a high proportion of free sorption sites for the binding of metals.
- Especially well matured compost may provide suppressive effects against soil born plant diseases. Continued research is needed in order to understand systematically the interactions of compost quality (as a result of input materials and composting process) and the suppressive effects.
- Compost application, even on good arable sites, can contribute to improve biological (soil fauna and microbial activity) and physical soil characteristics, and thus promotes the sustainable and multifunctional use of these soils

ORGANIC MATTER MANAGEMENT – A CONTRIBUTION TO SUSTAINABILITY

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Introduction and background

The application of organic matter to ecosystems has received increasing attention in many European countries in recent decades. This is due not only to the potentially beneficial effects of organic matter application, but also to the increasing availability of cheap sources of organic matter, such as sewage sludge and compost in industrialised countries. Within the European Community, a total of 7,432,000 t of sewage sludge dry matter was produced in 1996. This quantity is expected to increase by 35% by the year 2005 (Vetterlein & Hüttl 1999). A similar situation exists for compost.

With regard to the sustainability concept in Germany a matter cycling law was established in 1996, indicating that all waste material suitable for reutilization such as sewage sludge and compost, e.g. via application in agriculture, must in fact be reutilized and only those waste materials that can not be beneficially used e.g. for soil improvement purposes should be disposed on dumps or used for energy production. Also based on the sustainability concept, a few years later the German government passed a soil protection law, indicating, that soils should not be harmed by whatever management practise. As the application of organic waste materials such as sewage sludge and compost may not only have positive effects but may also cause ecological risks such as soil contamination with heavy metals or eutrification problems due to the input of high rates of N and P contained in these materials, clearly between these two regulations a conflict was produced. This controversial discussion has lead to the suggestion that in Germany specific types of application of organic matter, particularly of sewage sludge and compost for agricultural purposes, should be discontinued. Hence, with regard to the ecological effects of organic matter management, the question arises whether application of organic matter aiming at soil improvement can be seen as a contribution to the sustainability goal or not.

As there is a long tradition of organic matter application in agriculture much knowledge and experience has been gathered in this arena. Another option of beneficial ecological effects of application of organic matter may be disturbed ecosystems resulting e.g. from large scale open cast mining-activities. A common characteristic of such devastated areas is the lack of vegetation and thus of organic matter. Since the presence of organic matter and its decomposition as well as its microbial mineralization is considered a key component for nutrient and carbon cycling in terrestrial ecosystems, the course of development of these parameters has received considerable attention in reclamation and restoration research. Therefore this paper will present some recent results on organic matter management in disturbed ecosystems using the Lusatian lignite mining district as a case study.

Sustainability

The modern concept of sustainability is based on the integration of three dimensions: the ecological dimension, the economic dimension and the socio-cultural dimension. The activities of our societies today must therefore be based on the goal that the ecological, economic and socio-cultural development of future generations has the same potential as today. For example, the consumption of natural resources by today's societies must not lead to deficiencies for future generations. In this context, besides the rate of consumption and the proposed availability of natural resources also the demographic development and technological innovation potentials are important parameters for the adequate prognosis of a sustainable development.

Organic matter management means the application of residual organic matter such as compost or sewage sludge (biosolids) to improve soil properties or to accelerate pedogenesis. However, this soil treatment option must always aim at the improvement of at least one soil function (i.e. regulation function, transformation function, production function) and at the same time must not impair any of these soil functions.

Soil organic matter

Soil organic matter (SOM) is all in soil contained dead (and living (Jenny 1980)) biological matter and relevant metabolites as well as organic matter applied by man such as organic waste materials, pesticides or organic matter input to soil via atmogenic deposition (*c.f.* Schachtschabel et al. 1992). Humus is defined as portion of SOM with dark coloured organic tissue that is too small or too disorganised to be recognised with the naked eye as such (Jenny 1980). About 60% of SOM is represented by humic substances (Varanini & Pinton 1995) with estimated half-lives ranging from hundreds to thousands of years (Jenkinson & Rayner 1977).

SOM is an important energy source for soil organisms. The activity of soil organisms is a major cause for increased soil pore volume and enhanced water percolation which is important especially for soils high in clay and silt content lacking larger pore size classes (Oades 1984). Organic matter may form complexes with mineral particles resulting in a stabilisation of aggregate structure. SOM enrichment in sandy soils may result in a higher water-holding capacity (Scheffer et al. 1984). Furthermore SOM may reduce water erosion at the soil surface (Jenny 1980). The conditions for plant growth are improved due to the relatively large amount of nutrients stored in SOM. Organic matter itself is not essential for plant growth, although it has been suggested that humic substances can have a direct effect on plant growth, assuming a hormonal action of humic substances (Varanini & Pinton 1995). Humic substances contribute to soil cation exchange capacity and, due the potential to form complexes with metal cations, an immobilisation of heavy metal components in polluted soils may be achieved.

Impact of residual organic matter on soil

Natural soil functions may be improved but also harmed by application of residual organic matter. Although often an increase in SOM is observed as a result of organic matter application, the accumulation rates differ widely and no general relationship between the amount of organic matter applied per unit of time and the rate of accumulation can be found (Vetterlein & Hüttl 1999; Delschen & Necker 1996).

Soil biology

The impact of residual organic matter to soil biological activity varies as can be seen from a large number of experimental results (Vetterlein & Hüttl 1999). Compost and sewage sludge amendments can increase soil respiration by 15 to 40% (Dar & Mishra 1993). On the other hand Brendecke et al. (1993) reported no effects on soil respiration after application of organic matter. Nevertheless, significant effects on soil respiration rate are often obtained only at higher application rates (Olfs et al. 1994). Little information is available on long-term effects of organic matter application on soil biology (Vetterlein & Hüttl 1999). An increase of soil enzyme activity due to organic matter amendment was shown e.g. by Martens et al. (1992). Contradictory results also exist concerning the number of soil microorganisms after compost application (Seaker & Sopper 1988, Brendecke et al.1993).

Soil physics

With respect to the impact of residual organic matter on soil physical properties, several studies report decreased soil bulk density and lower penetration resistance after sewage sludge or compost application (Tester 1990, Tenholtern et al. 1996). Increased soil aggregate stability due to organic waste application was described by Piccolo & Mbagwu (1990) and also by Sahin (1989). However, these authors found no correlation with the rate of application and aggregate stability. In contrast, Brendecke et al. (1993) found no effect on aggregate stability at all after application of residual organic matter. Pagliai & Antisari (1993) reported a shift in pore size distribution being related to organic matter amendment.

Soil fertility

Due to the nutrient content of compost and sewage sludge the application amount of mineral fertilizers can be reduced in agricultural practices aiming at improved nutrient supply. However, related to the application of organic material it is difficult to predict the availability of nutrients, especially N. The decomposition and mineralization of residual organic matter depends on the specific composition of the material as well as on site conditions, e.g. temperature, soil water content and soil texture. Potential N-losses into ground water (Wilden 2000) or into the atmosphere stemming from applied organic matter need to be considered. While for sewage sludge the risk of N leaching is high, due to lower N and higher lignin contents, the mineralization rate of compost is lower and hence, the risk of N-leaching losses from compost is generally low (Sikora & Yakovchenko 1996; Wildhagen et al. 1987). In view of an optimum fertilizing practise the amount of nitrogen and phosphorus mineralized from compost and sewage sludge has to be monitored with respect to nutrient demand of the respective plant crops and eutrification of e.g. soil or ground water. Other risks of organic matter application can be nutrient surplus, input of heavy metals and organic xenobiotics.

Concept of Matter Cycling Management

The German matter cycling law aims at the reutilization of waste material. Only when residual organic materials can not be used they shall be disposed or utilized for energy production. In this context this “re-cycling” law shall help to protect natural resources. The German soil protection law was passed to restore deteriorated soils. In addition, this law also states that no form of soil management shall lead to soil deterioration. As the application of organic waste materials such as sewage sludge and compost may not only have positive effects but may also cause ecological risks these two regulations are somewhat controversial. From this controversy it becomes clear, that the decision of application or disposal of residual organic matter is not just scientifically or economically but finally politically driven.

Due to the increasing supply of residual organic matter in industrial countries a concept for a sustainable matter cycling management as well as for an adequate life cycle assessment is needed. Fig. 1 illustrates the course of organic matter in a cycling system. Products from agricultural, forestry or from landscaping activities are traded at the market and are used by consumers. From this consumption residual organic matter such sewage sludge or compost results. Specific regulations determine the fate of these materials: they may be utilized for soil management purposes, they may be disposed or they may be subject to alternative treatments, e.g. composting, eventually allowing for ecologically compatible reutilization in agriculture, landscaping or reclamation of disturbed areas. In addition to the application or disposal these materials may also be used for energy production.

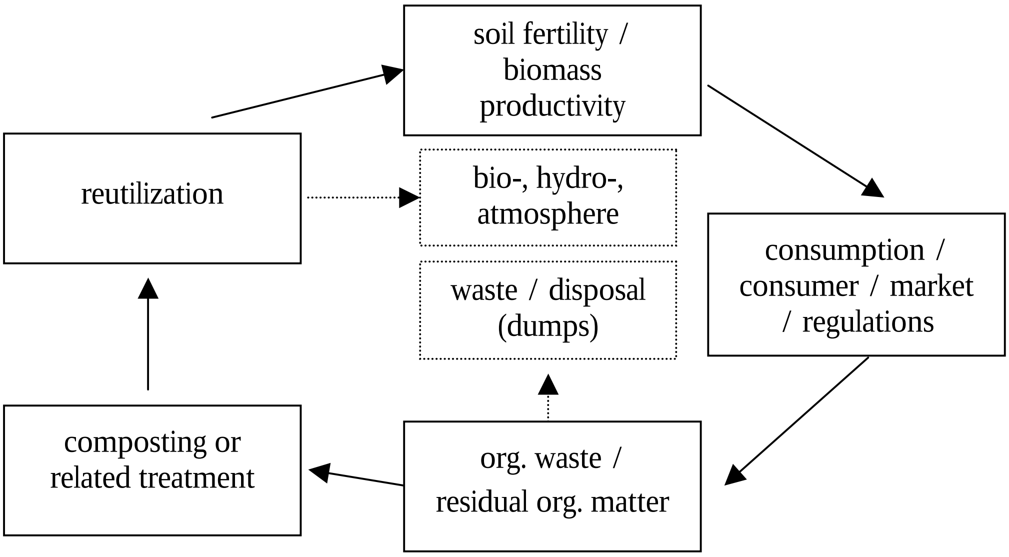

Fig. 1. Cycling of residual organic materials

Use of residual organic matter for reclamation practices

Beside the utilization of residual organic matter in specific agricultural management practices application of organic matter for reclamation of disturbed ecosystems, e.g. open cast mining areas, can be of interest. Post-mining areas are generally characterized by low or completely missing vegetation, deficiencies in SOM and nutrients as well as by insufficient soil physical and biological properties.

Case study in Germany

In the Lusatian lignite district in eastern Germany – being one of the largest lignite mining areas worldwide – more than 80.000 ha of land have been devastated by open cast mining operations.

Before 1990 a separation of lignite and pyrite containing overburden and lignite and pyrite free overburden was technically not feasible. Therefore, 60% of the devastated area consists of lignite and pyrite containing spoils (Katzur 1998). The lignite and pyrite containing spoil substrates of the Lusatian mining district are marked by very high acidity and electric conductivity values due to chemical and/or microbiological pyrite oxidation processes as well as by a very low content of pedogenic organic matter and nutrients. For successful reclamation, high application amounts of basic materials like limestone or alkaline fly ash are required to neutralize soil acidity and hence create the potential for plant growth. Due to the lack of nutrients in these spoil substrates mineral fertilizers are conventionally applied as a fundamental reclamation measure. Because of the sandy texture of these spoil substrates the risk of nutrient losses from the mineral fertilizers via seepage water leaching is relatively high.

An alternative treatment to the amendment of mineral fertilizers might be the application of organic residues like compost or sewage sludge. To test this alternative reclamation approach a comprehensive research project focussing particularly on the restoration of soil ecological functions utilizing the application of suitable organic waste materials is carried out since 1995 in the post mining landscape of the Lusatian lignite district.

In this study Meyer et al. (1999) investigated the impact of residual organic matter and fly ash on microbial (e.g. *Thiobacillus ssp.*) and chemical pyrite oxidation, both under field conditions as well as in column tests in the laboratory. For the column experiment a model spoil enriched by pyrite was mixed with fly ash and mineral fertilizer, reflecting the conventional reclamation practise in the Lusatian open cast lignite mining district. Furthermore, the test columns were inoculated with different cell numbers of autochthonous acidophilic bacteria or with a commercial strain of the genus *Thiobacillus*. As a result of this laboratory study the ratio of sulphate-S to total S, i.e. the degree of pyrite oxidation increased within 28 days and could be related to the inoculated cell numbers of bacteria independent of the origin of the bacteria. In a second column test the spoil was mixed with compost and sewage sludge, respectively and inoculated with autochthonous bacteria, which were isolated from the test spoil. After 127 days of incubation the degree of pyrite oxidation reached about 70% in the treatment with residual organic matter but only about 40% in the treatments without organic matter application. Meyer et al. (1999) found that the application of compost or sewage sludge seemed to promote the weathering of pyrite, as the ratio of sulphate-S to total S increased more rapidly in the organic residue treatments compared to the conventional mineral fertilizer application. In contrast, in the field study no differences in spoil pyrite-S contents between the various treatments could be detected. The reasons for this finding might be the high initial variability and the relatively low amounts of pyrite contained in the spoil at the test site.

Another investigation in this case study was a soil microcosm experiment carried out by Blechschmidt et al. (1999). With this experiment the rate of carbon and nitrogen turnover of lignite mine spoils amended with organic materials was observed. Various amounts of compost (22; 44; 66 t ha^{-1}) and of sewage sludge (19; 38; 57 t ha^{-1}) were applied to the experimental pyrite and lignite containing substrate. The C-losses measured via CO_2 emission from sewage sludge were significantly higher (3.2 - 4.7% of C_t) compared to the compost treatments (1.5 - 2.7% of C_t) being apparently related to higher microbial activities in the sewage sludge treatments than in the compost variants. Almost 9% of N_t applied with sewage sludge was lost over a period of 150 days mainly as NO_3-N by way of seepage water leaching. The N_t -losses from compost treatments were three times lower and occurred in similar NH_4-N and NO_3-N quantities. Sewage sludge applications showed a slightly increased N_2O emission at the beginning of the experiment. In summary it was found that the application of residual organic matter to lignite mine spoil influenced the C and N turnover rate especially during the first 60 - 80 days after treatment. There is a potential risk of NO_3^- leaching loss from sewage sludge application. However, it must be noted that in the microcosm experiment plants and hence plant uptake were not included which of course would reduce nutrient leaching losses by way of seepage water output due to plant uptake.

Wilden et al. (2001) investigated the element budgets of two mine sites after application of compost, sewage sludge or conventional mineral fertilizer. The effects of compost, sewage sludge and mineral fertilizer treatment were compared e.g. with regard to their relation to soil solution chemistry of both a lignite and pyrite containing spoil (WEB site) as well as a lignite and pyrite free spoil (SEE site). The chemical properties of the investigated spoils are shown in Table 1. Common characteristics of the two test sites are a sandy soil texture, a low content of pedogenic organic matter as well as a low nutrient content.

Table 1. Chemical properties of two Lusatian spoils (0 – 100 cm depth, mean values) (Wilden 2000)

	pH	**EC**	**C**	**N**	**S**	**Ca**	**Mg**	**Fe**	**Al**	**CEC_{eff}**
	(H_2O)	µS/cm				mg/g				cmolc/kg
WEB	3,3	2280	13	0,3	3,4	3,3	0,4	5,5	7,5	3,0
SEE	5,5	130	4	0,4	<0,1	0,6	0,3	2,3	4,0	2,2

The extremely acidic WEB site was ameliorated with 135 t ha^{-1} lignite fly ash (equivalent to 38 t $CaCO_3$ ha^{-1}) and due to much higher pH-values at the SEE site only 20 t ha^{-1} limestone were applied (equivalent to 9 t $CaCO_3$ ha^{-1}). After this conventional site amelioration three treatments, i.e. compost, sewage sludge and mineral fertilizer were established on plots of 0.1 ha each at both sites. The mineral fertilizer plots were treated with 120 kg N ha^{-1}, 100 kg P ha^{-1} and 80 kg K ha^{-1}, at the sewage sludge plots 19 t d.m. ha^{-1} polymer stabilized anaerobically digested sludge cake were applied and 22 t d.m. domestic organic waste were amended at the compost plots (Table 2). Two-year-old Scots pine seedlings (*Pinus sylvestris* L.) were planted within 2 days after amelioration (12.800 trees ha^{-1}). Furthermore wild rye grass (*Secale multicaule* METZG.) was sown in (10 kg ha^{-1}).

Table 2. Selected chemical parameters of compost and sewage sludge applied at the test sites (WEB; SEE) (Vetterlein 1999)

	pH	**Organic matter**	**C_t**	**N_t**	**C/N**	**P_t**	**K_t**	**Ca_t**	**Mg_t**	**Zn_t**
	(H_2O)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(ppm)
Compost	7.9	35	18.9	3.1	9	0.5	1.2	4.6	0.4	322
Sewage sludge	7.0	50	23.1	3.3	7	2.0	0.3	3.9	0.3	1246

The application of sewage sludge caused an increase of NO_3^- concentrations in the topsoil up to 1.8 mmol NO_3^- l^{-1} at the WEB site and 2 mmol NO_3^- l^{-1} at the SEE site due to mineralization of N contained in this material. At the WEB site, mineralized N seemed to match perfectly with both, plant N demand and immobilization by microorganisms. Therefore, no nitrate leaching could be measured beyond the root zone. NH_4^+ concentrations increased up to 1 mmol l^{-1} at WEB site after sewage sludge application. With increasing soil depth and decreasing pH values, NH_4^+ was the dominant N-form in the soil solution at this site. According to Hons & Hossner (1980) lignite might adsorb large amounts of NH_4^+. Therefore, the mean concentration of NH_4^+ in the subsoil might be attributed to desorption of NH_4^+ from lignite. At the lignite free SEE site the NH_4^+ concentrations were indeed very low (max. 0.3 mmol l^{-1}) (Wilden et al. 2001). In contrast to the supply of mineral fertilizer, application of sewage sludge resulted in a significant increase of biomass production (Vetterlein 1999). This study revealed that application of 19 t ha^{-1} sewage sludge at the WEB site provided nutrients for plant growth for at least three vegetation periods without adverse effects on soil solution quality. In contrast, at the SEE site sewage sludge application resulted in increased NO_3 leaching losses during the second year after treatment. However, also at this site positive treatment effects on biomass production were eventually balanced with NO_3 availability. Therefore, an application rate of 19 t ha^{-1} sewage sludge can be considered appropriate for both sites (Wilden et al. 2001).

Compost application did not increase NO_3^- or NH_4^+ concentrations in soil solution on either of the test sites. These observations might best be explained by a lower mineralization rate of compost compared to sewage sludge. In a laboratory study Mayer & Hüttl (1999) recorded potential N mineralization of the sewage sludge plot from both sites to account for 16 - 18% N within 28 days, whereas the mineralization rate in the compost plot was only 2 - 4% for the same time period. All N released by mineralization of compost was taken up by the plants or was immobilized by microorganisms. Therefore, N fluxes in the compost plot were very low. Plant N uptake accounted for 2% of total N input at the WEB site and for 4% at the SEE site. This difference can be attributed to higher microbial activity and biomass production at the SEE site compared to the WEB site (Mayer & Hüttl 1999; Vetterlein 1999). Thus, application of 22 t ha^{-1} compost provided N for plant growth in the longer run but was insufficient for the short-term N plant requirement. Furthermore, Wilden (2001) measured a strong increase of K and Cl fluxes at both experimental sites after compost application. Compost application provided high amounts of K, which could not be taken up by the plants and therefore K was leached to a high extent. PO_4-P fluxes were not increased following compost application, indicating either little mineralization of organic P or immobilization of PO_4 as Fe, Al or Ca phosphate. Plant P-uptake as based on total P-input accounted for 2% at the WEB site and 4% at the SEE site (Vetterlein 1999).

In contrast to sewage sludge, compost application did not result in a significant increase of biomass production (Vetterlein 1999). Thus, the amount of N and P applied with 22 t ha^{-1} compost was not high enough to markedly promote biomass production at the two experimental sites. To support adequate plant growth it seems therefore necessary to accompany compost application with mineral fertilizer amendment.

Conclusions

Organic matter is a key component for nutrient and carbon cycling in terrestrial ecosystems. With regard to the application of organic matter to terrestrial ecosystems much is known from agricultural treatments. However, besides the traditional utilization of residual organic matter in arable management to increase soil fertility, to improve soil physical properties and to stimulate soil biological processes also the application of organic materials in restoration or reclamation of disturbed areas can have beneficial effects e.g. on stimulating the development of soil ecological functions, on accelerating pedogenesis in general and even on initiating ecosystem development.

Besides the conventional application practices for agricultural and other purposes this more recent potential of applying organic materials to devastated soils or disturbed areas is of interest and needs further attention, both in research and administrative regulation.

In any case adequate standards related to the quality of residual organic matter that might eventually be added to soils must be established and observed. With regard to the application of organic matter it is also important to note that there exists a large variety of different qualities of organic matter materials.

In this context, quickly changing political decisions need to take into consideration that scientific research – particularly when facing real world ecological aspects – is often long-term oriented. This situation indicates that there may be a time conflict as the need of short-term political decisions may not be paralleled by sound scientific results which can often only be achieved by way of long-term research.

Finally it can be stated that site and crop specific organic matter management utilizing appropriate qualities of organic substances and clearly aiming at soil improvement aspects can be considered as a contribution to sustainability.

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Session I

N and C pools – what is their fate in compost amended systems?

INTRODUCTION

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Organic Matter – its importance in soil management

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 a 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. micro-organisms 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 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 hyphae, spores, seeds and animal remains.

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.

The potential roles played by SOM

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 1, based broadly on Stevenson (1994) lists some of the benefits claimed for SOM in soils.

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 is further major influence of SOM.

Table 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

Organic Residues

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 presents information on turnover times for some of the key fractions of SOM.

Table 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.

Decomposition of organic materials applied to soil

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

1. C content, C:N ratio
2. Soil temperature
3. Soil moisture
4. The status of the soil including soil nutrients and pH
5. Method of application of the organic residues (soil incorporated> surface applied)
6. 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 micro-organisms. 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 micro-organism. 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.

Why is organic matter added to soils?

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 the timing of the applications and should be considered when determining the nature of the materials to be applied. If an attempt is being made to restore SOM levels in a degraded soil 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.

Models to simulate soil organic matter turnover in soils

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.

The model (Fig. 1) proposed by Jenkinson and co-workers at Rothamsted Experimental Station in the United Kingdom (see for example Jenkinson and Rayner, 1977; Jenkinson 1990), 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.

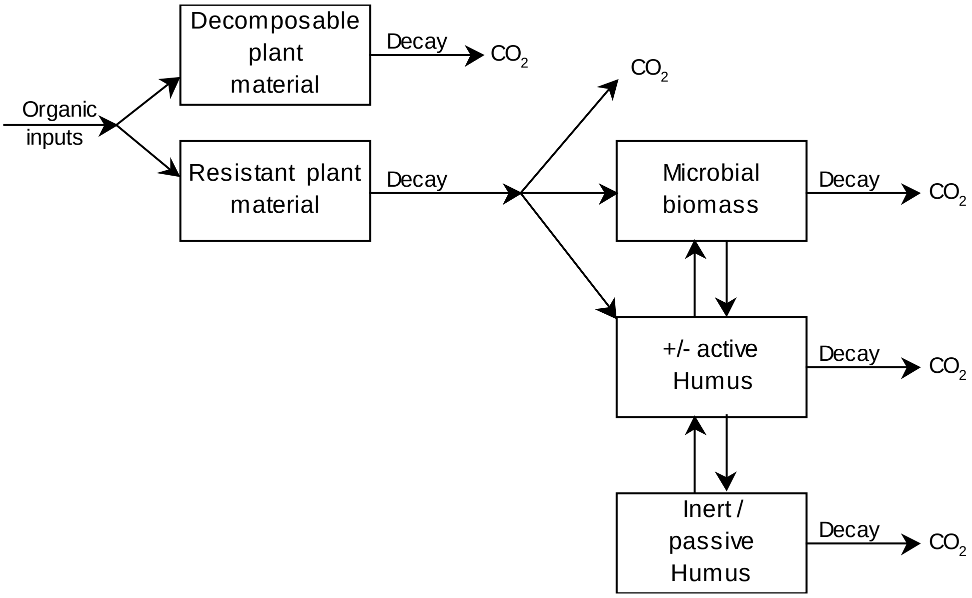


Fig. 1. The Jenkinson "soil organic matter model" (Jenkinson, 1990; slightly modified).

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.

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 3. Changes in SOM on three rotations with two contrasting managements

Rotation	**Treatment**	**% organic matter**	**% 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 t 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.

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 and Richter suggest that for the majority of loess soils the equilibria 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.

Carbon sequestration and reproduction

Composts from source separated collection systems for organic waste typically show an organic matter (OM) content between 25 and 40 % d.m.. The values depend on the composition (C/N ratio) of raw materials and the stage of mineralisation. For example values for C/N ratio and total N content of biowaste composts derived from source separated kitchen waste and green waste are shown in Table 4.

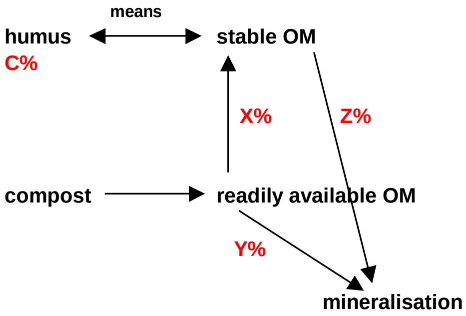
Table 4. Organic matter und C / N-ratio in biowaste composts

		Nr. of samples	10th percentile	25th percentile	***median***	75th percentile	90th percentile
Org. matter	% d.m.	220	20,6	25,1	***31,0***	36,3	44,2
TOC	% d.m.	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
N_{tot}		202	0,88	1,10	***1,39***	1,70	2,01

Source: Austrian composts from source separated kitchen and garden waste; Amlinger (2000)

The stability of compost OM may be an important factor influencing the accumulation achieved in the soil., but even more important are climatic, management and soil parameter itself as described above.

Hogg and colleagues (Hogg et al., 2002) calculated a model for potential C-sequestration in compost amended soils The model is based on the following basic assumptions.



C ranging from 1 to 5%

X ranging from 10 to 20 %

Y ranging from 10 to 30%

Z ranging from 0,1 to 2%

Using the figures X = 20%, Y = 10%, Z = 1.5%, and with an initial organic matter concentration of 3.5%, it is possible to plot the effects of different rates of compost application (0, 5, 10 and 15 tonnes dry matter per hectare a year) on the level of organic matter in the soil. This is shown in Fig. 2.

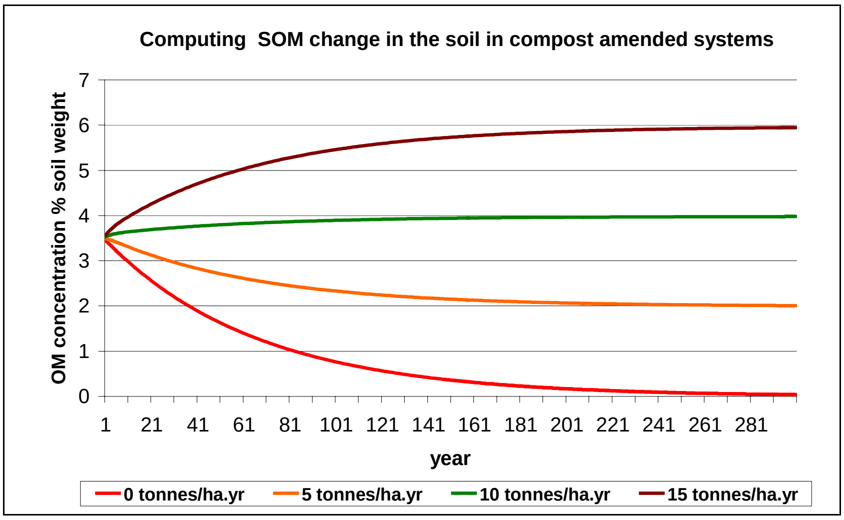


Fig. 2. Effect of different rates of compost application on soil organic matter levels (following a model by Hogg et al. 2002)

Increases of SOM as a result of compost application has been reported by many authors (e.g. Bohne et al., 1996, Buchgraber, 2000 Hartl, 1999, Parkinson et al., 1999). Additions of 5 – 10 t d.m. compost equal 1.5 – 3 t organic matter and this is considered to balance the yearly decay of *humus in* arable cropping systems. Long term repeated use of compost increases the soil C content (Gutser, 1999).

Based on a 6 year field trial on a sandy loam soil Gutser (1996) computed the highest *"humus reproduction coefficient"* (K_{HR} : t Humus-C / t 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 % (see Table 5).

Table 5. Humus reproduction of different organic soil amendments (Gutser, 1996)

K_{HR} = t Humus-C / t fertiliser-C

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) Kundler (1986)

2) Average Orientation values

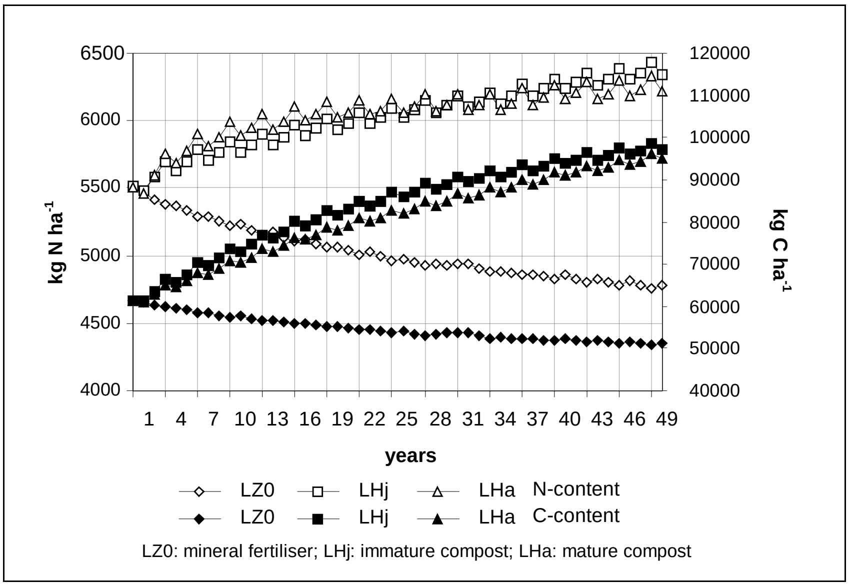
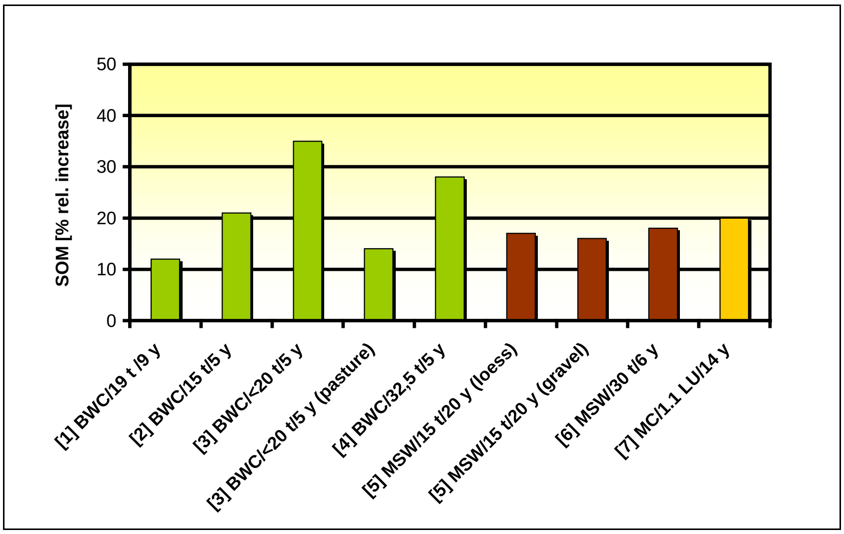


Fig. 3. Model (DAISY) for C and N performance during 50 years without and with compost application (30 t f.m. $ha^{-1}3y^{-1}$) (Stöppler-Zimmer et al., 1999)

Modelling (computer simulation-model DAISY, Stoppler-Zimmer et al., 1999) long term compost management (loamy soil, compost: 30 t 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 increased duration of compost application (Fig. 3, Stöppler-Zimmer et al., 1999).

Fig. 4 gives some examples for the changes in SOM from medium and long term field trials with regular compost amendments at moderate application rates.

It can be concluded that depending on site and soil properties (temperature and precipitation regime, clay content, background SOM content in soil and the resulting average mineralisation rate) and soil management impacts (arable cropping or pasture land) beginning with 7 - 8 t d.m. yearly compost application the organic carbon loss caused by soil cultivation may compensated (Diez and Krauss, 1997). In some of the trials described in the literature SOM even increased with this level of regular additions.



BWC…biowaste compost; MSW…solid waste compost; MC…manure compost; LUlifestock units per ha; ‘19 t’ … 19 tonnes f.m. compost per ha*year

[1] Aichberger et al., 2000; [2] Bragato et al., 1998; [3] Buchgraber 2000; [4] Hartl & Wenzl, 1997; [5] Diez & Kraus, 1997; [6] Businelli et al., 1996; [7] Alföldi et al., 1995

Fig. 4. Relative increase of SOM in compost amended soils in several field trials

Effects of compost on the nitrogen regime in agricultural soils

General aspects

The assessment of compost nitrogen dynamics under field conditions is discussed broadly and plays an essential role in the frame of effective optimisation of compost fertilisation. Since the major part (≥ 90 %) of total compost-N is bound to the organic N-pool (Amlinger & Götz, 1999), depending on various conditions, such as kind of substrate used, composting process as well as climate and soil properties, cropping and soil management etc. the availability of N for the plant is low. In consideration of water conservation requirements and sound plant nutrition management, methods for the estimation of the availability and binding dynamics of compost N in the short and long term are required.

Nitrogen load as well as its mobilisation rate is strongly linked to the level of soil organic matter (SOM) and to the relative magnitude of the active fraction of the total SOM, or to the more passive pool which is currently undergoing alteration (Nortcliff, 1999). Net-immobilisation or net-mobilisation depends of the balance of the mineral N-pool over a defined period. For the net-mineralisation (total mineralisation minus immobilisation taking into consideration liquid and gaseous losses) quantities in the range 50 – 150 kg N ha^{-1} during the vegetation period are reported (Neeteson, 1995).

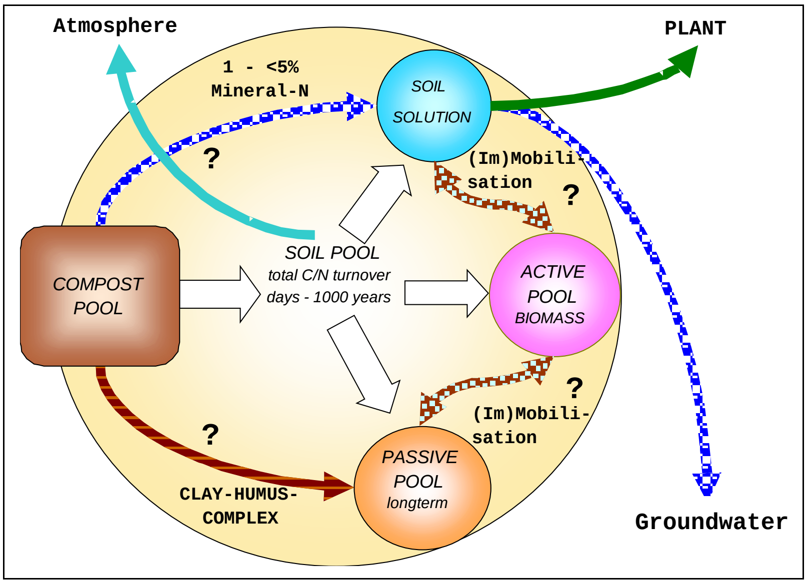


Fig. 5. The still sparely known fate of compost-N in SOM-pools

Fig. 5 provides a framework for considering the potential fate of compost derived N in the soil. For judging the potential N-release into the gaseous phase and the risk of leaching of compost-N it would be essential to quantify the changes in soil-N-pools after compost application. A scientific view on compost utilisation is only possible when the temporal dynamics of the material fluxes under different site conditions can be described. However, the new balance after input of organic material is mainly influenced by soil type, crop rotation and humus management (recycling of plant residues). As a first approach The C/N ratio of the soil indicates the tendency of mobilisation or immobilisation of nitrogen (Table 6).

Table 6. Trends for N-mobilisation and immobilisation related to C/N ratio (Husz, 1999)

C/N-ratio pasture land	C/N-ratio arable land	trend
< 7.5	< 8	N-release distinct
7.5-8.5	8-9	N-release
8.5-9.5	9-11	balanced
9.5-10.5	11-14	N-binding
> 10.5	> 14	N-binding distinct

To evaluate the mineralisation (availability) of compost-N and to estimate the amount available for plants over a certain period several experimental and calculation methods are possible:

- Laboratory incubation tests under constant conditions (temperature, water content of the substrate with and without cultivation of crops) with or without periodic percolation of the mineralised N
- Field trials to evaluate the N-efficiency in terms of comparative yield or N uptake respectively, relative to control or mineral fertilised plots
- N-leaching tests on field scale with lysimeter installations or suction cups as well as regular measurements of mineral N in the leaching horizon
- Model based calibration of N-mineralisation kinetics

Incubation tests

In Table 7 some citations with key results of incubation tests are assembled. Even under optimised temperature and water conditions the mineralisation rates only in one experiment with FYM compost exceeded 15 % of total compost-N. Even immobilisation during the initial stages was observed upon application of compost rich in C. Nevertheless, the authors point out that laboratory results reflect only the potential and not the real dynamics under field conditions.

Table 7. N-Mineralisation of different compost types as found in incubation tests: N-availability in % of Ntot supply.

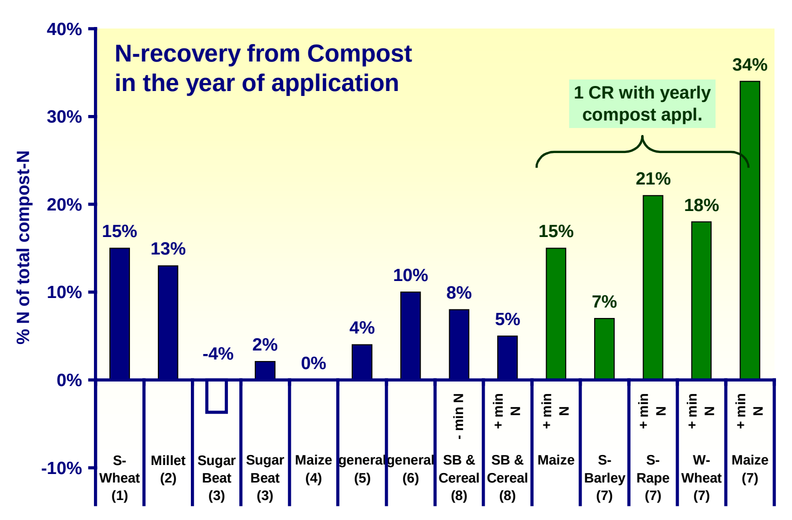
Source	**Incubation** *[weeks]* *[°C]*	**Compost** *[type]* *[amount or conc.]*	**Net-mineralisation** *[% of N_{tot}]*	**Remarks**
(1)	12 weeks 20 °C	yard waste 38 composts 100 % compost	8 – 11 %	50% short term, 13% med. term immobilisation
(2)	52 weeks 28 °C	FYM 60 t f.m. ha^{-1}	25 % 34 %	→ loamy soil → sandy soil
(3)	32 weeks 30 °C	FYM & MSW 5 and 15 % compost	15 %	
(4)	16 weeks 22 °C	4 FYM 0,05, 0,1, 0,2 % N	0 – 14 %	at high C/N → immobilisation
(5)	29 weeks 15 °C	SS & Biowaste 300 kg N	= control	undisturbed soil cores measured as N-release in percolate

Compost from: FYM = farm yard manure; SS = sewage sludge; MSW = municipal solid waste; f.m. = fresh matter

(1) Berner et al (1995); (2) Cheneby et al (1994); (3) Hadas & Portnoy (1997); (4) Hébert et al. (1991); (5) Insam & Merschak (1997)

Many field trials with different types of compost and application schemes, crop rotations and all types of soil and climatic conditions have been undertaken since the late 1980ies. Fig. 6 and 7 summarise some examples from the literature indicating the N-efficiency of compost fertilisation systems in the year of application (Fig. 6) and on average within the entire crop rotation (Fig. 7). N-efficiency is expressed as % N of the total compost-N applied. This is in most cases calibrated with control and mineral fertilised plots. Citation (11) in Fig. 7 shows the increased N utilisation from compost after seven 3-year rotations (sugar beet-wheat-barley) .

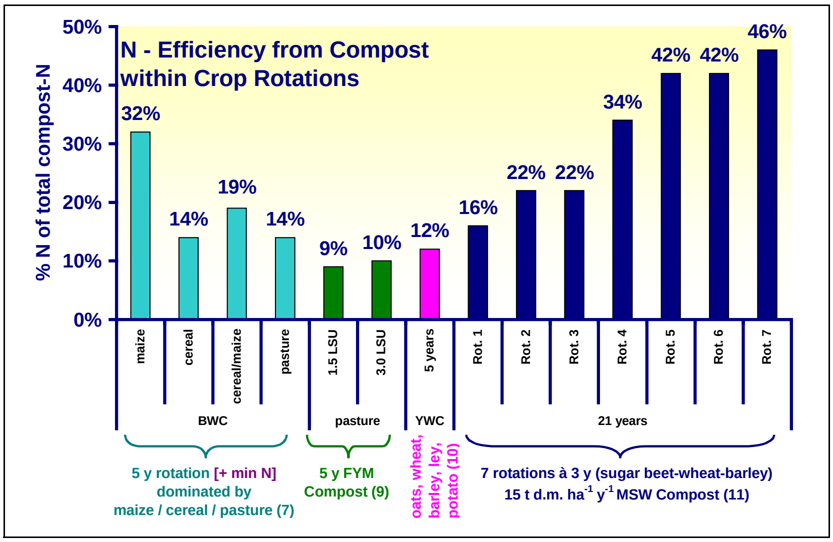
Some results from field trials



- min N = without supplementary mineral N; + min N = with supplementary mineral N; SB = sugar beet
(1) Gagnon et al. 1997; (2) Schlegel 1992; (3) Asche et al. 1994; (4) Frei Ming et al. 1997; (5) Ebertseder and Gutser 1995; (6) Gutser 1996; (7) Buchgraber, 2000; (8) Diez and Krauss, 1997

Fig. 6. N-Recovery from Compost in the year of application (CR = crop rotation)

As a common experience these experiments indicate that (1) N-effect of compost application in general does not exceed 15 to 20 % of total N-supply in the first year (with immobilisation phenomena in some cases) and (2) in the following years the residual compost N-pool is mineralised at low rates between 3 and 8 %, (3) with continuous compost amendments and crop rotations with high nutrient demand this ratio may increase. Mature compost may mineralise in a shorter time period than fresh compost.



LSU = livestock unit ha^{-1}; YWC = yard waste compost; FYM = farm yard manure; + min N = with supplementary mineral N
(7) Buchgraber, 2000; (9) Pötsch, 2000; (10) Berner et al., 1995; (11) Diez and Krauss, 1997

Fig. 7. N-Efficiency from Compost within Crop Rotations

Leaching of nitrogen in compost amended soils

The most critical issue discussed as related to continuous compost applications is the potential danger of uncontrolled N-leaching as a result of the build-up of organic N-pools for which the mineralisation dynamics may be predicted with great uncertainties. The question of N leaching by percolation or residual mineral N in the leaching horizon has been investigated in many field trials as well as in lysimeter stations and incubation tests with soil columns. It may be concluded that with practical compost application rates the site-specific leaching for NO_3-N is enhanced compared to variants without fertilisation by 0 to 50 kg N ha^{-1}. Furthermore some papers indicate that the biggest amount of NO_3 is found in the upper soil layer (0 – 60 cm). Despite these findings, in terms of water protection high amounts of compost in one or repeated applications are not recommended, at least for well drained soils (sandy textured). Data on N-release after compost application are summarised in Table 8.

Table 8. Changes in soil mineral–N after compost application (selected data)

Source	**Horizon** ***cm*** ***soil***	**Compost type** ***amount ha^{-1}*** ***applic. priod***	**N_{min} ha^{-1}** ***compared to control***	**Remarks**
(1)	0 - 90	Biowaste 2 x 30 t in 5 y	20 kg above mineral N	after 2nd compost appl. Max: Δ = 70 kg
(2)	0 – 90 loamy silt	Biowaste 130 t in 5 y	max 49 kg > „0“	permanent rye rotation varied application rhythm
(2)	0 – 90 loamy silt	Biowaste 14 – 37 t y^{-1} over 6 y	max 5 - 23 kg > „0“	→ cereals & potatoes
(3)	0 – 90 loam & sand	Biowaste 30 t + min N 100 t	+/- compared to NPK	no differences at moderate amounts of 30 t + supplement. mineral N
(4)	0 – 150/300 silty loam	FYM 0 – 17.8 t d.m.	no effect	in ‘leaching horizon’ (150 – 300 cm)
(5)	0 – 60 loamy silt	Biowaste 80 t f.m.ha^{-1} 2 x in 5 years	34 % > „0“	Max: 120 kg in 0-60 cm in spring

y = year; FYM = farm yard manure; d.m. = dry matter; f.m. = fresh matter

(1) Pape and Steffens (1998); (2) Hartl (2000); (3) Stöppler-Zimmer and Petersen (1995); (4) Schlegel (1992); (5) Amlinger and Walter (1993)

Some preliminary conclusions

Depending on compost properties as well as on soil and cultivation conditions the immediate N-effect of compost amendments in the first year amounts range between 5 and 15 % of the total N in the composts, and in each of the following years from 2 – 8. This has to be considered by computing mid term compost-N efficiency. The N-mineralisation dynamics is predominantly determined by the soil properties C_{tot} and N_{tot}, C/N ratio, soil texture and soil moisture conditions. Maturity of compost in the long run is of minor significance. However, initial immobilisation is more likely with less mature compost and with high C/N ratio, respectively, while in mature compost N-immobilisation has already taken place during the composting process. Under sandy soil conditions, an adapted N-consumption by crop rotation, or diminished application rates of compost, have to be considered. On silty and loamy soils, the danger for nitrate leaching is clearly reduced. Combining the yearly supplies in 2 to 3-year-loads (e.g. 25 – 30 t d.m. every three years instead of 8 - 10 t ha^{-1}y^{-1}) will probably lead to an improved N-utilisation. The experimental results justify a variable approach on nitrogen related spreading restrictions depending upon the environmental conditions. For authorisation schemes and N limitations in the framework of e.g. the Nitrates Directive (Council Directive 91/676/EEC), the Regulation 2092/91 EEC on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs or national water conservation rules, N availability factors for composts must be considered. This is strongly recommended to improve an agronomically and environmentally sound SOM management in compost fertilised farm systems.

There is a need for further investigation to establish whether the release of accumulated organic nitrogen in the soil by compost input can be satisfactorily controlled. Accordingly, long term compost fertilisation has to be considered in the framework of (1) space and time dependent demand by crops (2) farming system (livestock, supplementary fertilisers, soil cultivation, crop rotation) and (3) soil and site conditions. Regular measurements of critical soil parameters (SOM, nitrogen, at total and soluble amounts) as well as specified product design in terms of feedstock composition, and maturation schemes are recommended for professional compost management.

Above all, knowledge on the transfer dynamics between the N-pools of the soil is essential. Nitrogen and organic matter balance for evaluating the mineralisation dynamics of the active humus pool under organic (compost) fertilising systems will play an important role for sustainable soil management.

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HOW DO ORGANIC FERTILISER SYSTEMS INFLUENCE THE C POOL IN LONG-TERM EXPERIMENTS?

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Introduction

The organic substance is a precondition for the formation of the soil. It considerably influences the soil fertility and the soil properties that are relevant to the yield. It also affects the C and N cycle of the atmosphere and has therefore a high importance for the environment.

Despite intensive humus research in the last few decades the question on the optimal humus content is still not settled. In most investigations the total carbon content is taken into account, which may lead to incorrect conclusions, because the mineralisable part of carbon is important as well. This portion can, for example, amount in a sandy soil roughly 50 %, and in a loamy soil only 25 % of the total carbon content. To solve this question, long-term experiments are necessary which, whenever possible, have reached a steady state.

The definition and determination of soil organic matter (SOM) is still not clear as well. In the following we understand SOM according to Müller (1980) as **'the living and dead organic matter, which is integrated in soil, where the first represents the edaphone (autochthone microorganisms) and the latter the humus'**.

A direct analytical determination of SOM is practically not possible, with exception of clay- and carbonate- free soils. It is common to calculate SOM from the analysed content of organic carbon by multiplication with the factor 1.724 or 2 respectively. The real conversion factor lies. between 1.4 and 3.3. Because of this uncertainty it is more precise to work with the directly analysed content of C_{org}.

The carbon and nitrogen cycles in the soil/plant system are also not fully elucidated and quantified. They, however, are of particular and crucial importance, because:

- both elements are essential for the soil functions, but the ranges of favourable and harmful effects are very narrow
- both cycles depend strongly on external influences and are, therefore, difficult to control,
- they are subject to a strong site and especially weather dependent variability impeding their quantification.
- the diversity and stability of their chemical structures are insufficiently known.

To solve these open questions mainly two directions were pursued in the past. On the one hand intensive humus research (humus chemistry) was practiced to elucidate the chemical structures of SOM by developing fractionation methods. On the other hand empirical approaches were followed to quantify SOM by evaluating field and model experiments as well as by the simulation of different compartments of SOM. On this basis threshold values were derived. Between the results of both approaches there is still a big difference.

Long-term experiments represent an indispensable basis for the solution of these problems. The results allow to derive useful conclusions for a sustainable soil management.

Material and Methods

Investigations to the subject of this paper require long-term experiments with a correspondingly intensive data collection over many years, better decades. In particular the parameters 'organic carbon' and 'nitrogen' in soil, but also crop yield show high spatial and temporal variability. Significant results can, consequently, only be achieved with a corresponding number of replications in space and time.

The majority of investigations presented in this paper were done at the site Bad Lauchstädt. It is a Loess-Tschernozem (Haplic Chernozem) with 21 % clay, 110 m above see level, 484 mm annual precipitation and 8.7 °C mean annual temperature (average 1896-1995).

The 'Static Fertilization Experiment Bad Lauchstädt', initiated in 1902, represents the most important data basis.

From 1902 to 1977 differences in the Corg content had been observed amounting to 0.66 %, the flow equilibrium had been reached on all treatments (Fig. 1). This considerable differentiation was used to build a three-factor experiment with the test factors:

- organic fertilization (2 stages: „nil“ and „30 t/hectare FYM every 2nd year)
- C_{org} content (6 stages: 1.7 to 2.3 %)
- mineral N fertilization (5 stages: 0; 42.5; 85; 127.5; 170 kg N/hectare annually in the
- average of the crops: sugar beet, spring barley, potato, winter wheat).

Additional one model experiment was included.

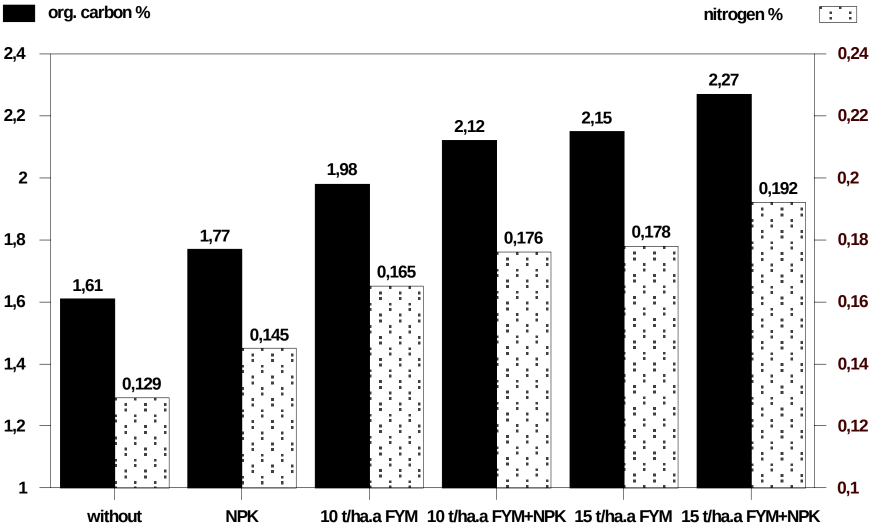

Fig. 1. Organic carbon and nitrogen in the main treatments of the Static Fertilization Experiment Bad Lauchstädt, 0 – 30 cm, average of all crops 1989-1992

The soil is tested annually on all plots. Corg is determined by means of dry combustion according to STRÖHLEIN, N is determined according to KJELDAHL.

Results and Discussion

The differentiation of the soil organic matter (SOM) according to its ability of mineralization

The SOM is closely correlated with almost all physical, chemical and biological soil properties. There is very little room for potential and at the same time useful changes since only the mineralizable carbon content can be taken into consideration. For mineral soil under the usual management conditions this content is between 0.2 and 0.6 % C (Körschens, 1997) which has been derived from numerous long-term field experiments as the difference between the long-term non-fertilized and the highest organic and mineral fertilized variant, respectively. Thus, the difference between the soils which are very well provided with organic substance and those which are very poorly provided is only 0.6 %. This differentiation is independent of the total carbon content, which consists of the mineralizable and the quasi inert part, i.e. in the sense of not being involved in decomposition processes. The latter is hardly contributing to the mineralization processes and is dependent on the local conditions, first of all on the soil texture, but also on the moisture content and the temperature. The inert C-content (Ci) of a black earth with 21 % clay in the Central German arid region, for example, is about 1.5 %.

Fig. 2 shows the linear regression between the clay content and the inert carbon and the decomposable carbon of 21 selected long-term experiments. The C_{org}-content of the nil plots is regarded as a criterion for the inert C-content.

Under field conditions this cannot be further reduced even under extreme conditions i. e. bare fallow. For agricultural use the optimum C-content of this Tschernozem is at approx. 2 %. Under the conditions of the light sandy soils of Brandenburg, near Berlin, with only 3 % of clay, the inert C-content at otherwise equal conditions is about 0.3 %; a total content of between 0.7 and 0.8 % has to be regarded as the optimum and can practically not be surpassed with justifiable amounts of organic fertilizer. This means, black earth with a C-content of 1.5 % can be considered as totally impoverished, whereas sandy soil with 0.8 % will be considered as very well supplied. The result of this is, that without the knowledge of the local conditions, especially of the soil texture, the total content of carbon does not allow any assessment of the soil's state of supply (Körschens, et al., 1998).

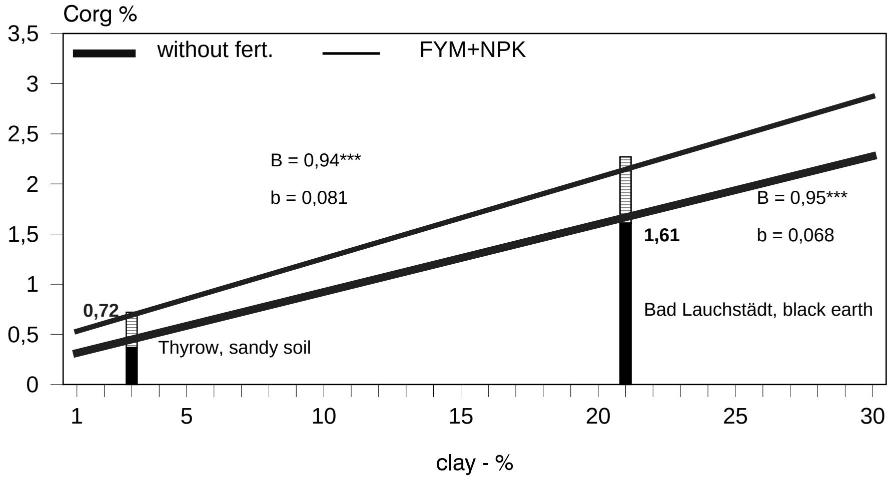

Fig. 2. Linear regression between C_{org} content of plots without fertilization as well as plots, fertilized with FYM+NPK and the clay content in 21 long-term experiments.

Fig. 3 shows the carbon contents of the unfertilized variant and of the manure + NPK fertilized variant of some selected experiments. It becomes evident that the differences between the locations are caused by the inert C-portions strongly differentiated in dependence on the clay content. In the result of long-term experiments the variant with an annual fertilization of 100 dt of manure per hectare has proved to be the optimum for the location of Bad Lauchstädt.

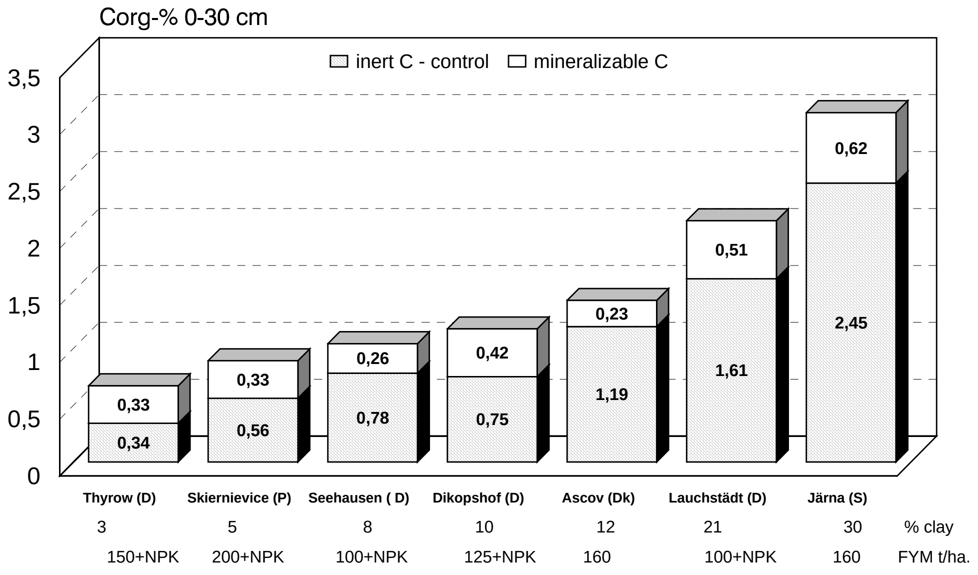

Fig. 3. Content of inert carbon (nil plot) and decomposable C (differences between "nil" and highest fertilization) in selected long-term experiments

The C_{min}-content also increases with clay content. Differences are considerably smaller and dependent on the amount of farmyard manure and mineral fertilizer added. The mineralization intensity declines with increasing clay content. The humification on soils rich in clay is thus approximately twice as high as on sandy soils.

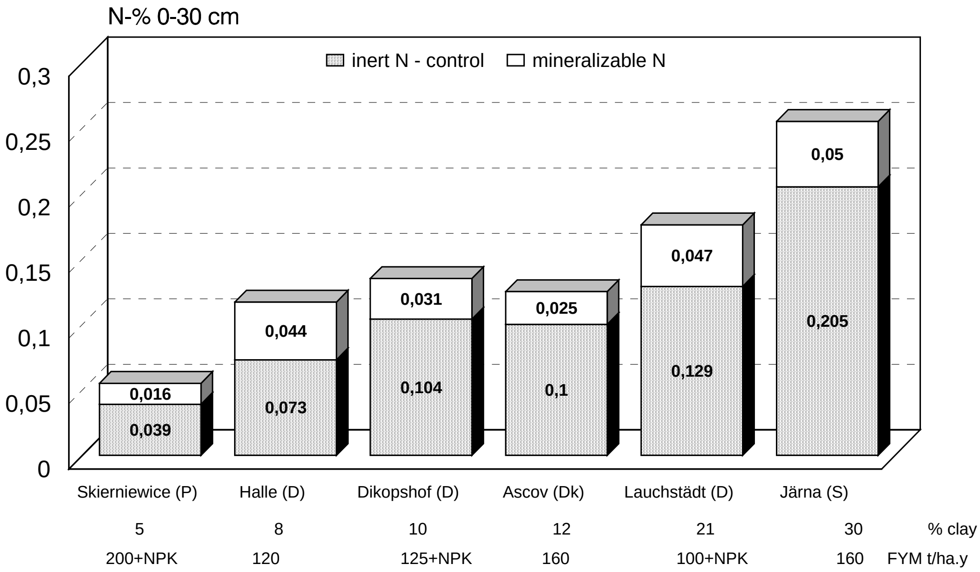

Fig. 4. Content of inert N (nil plot) and decomposable N (differences between "nil" and highest fertilization) in selected long-term experiments

Using an average of 24 long-term field experiments (Körschens, 1997) the difference between the control (zero input) and the treatment with the highest organic and mineral fertilization (applying justifiable amounts of fertilizer) was only 0.33 % (range 0.14 - 0.66 %). The N-contents of the long-term field experiments show similar relationships (Fig. 4).

N release

The N release from the soil pool is mainly determined by the soils state of supply with SOM and the mineralization conditions. This is illustrated by Fig. 5 and 6.

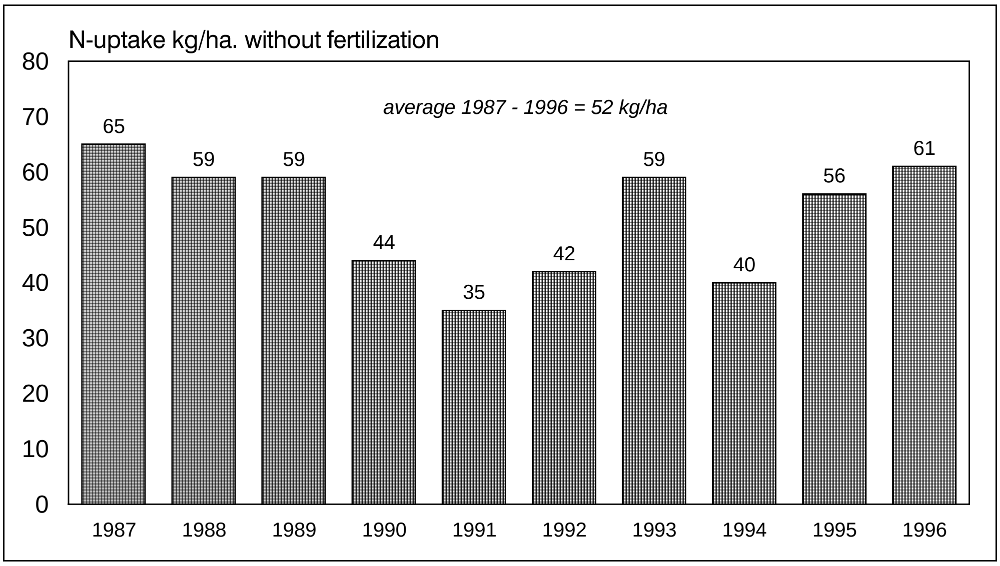

Fig. 5. N uptake without fertilization in the nil plot in the Static Fertilization Experiment Bad Lauchstädt

Fig. 5 shows the N-uptake of the treatment of the Static Fertilization Experiment Bad Lauchstädt, which has remained unfertilized since 1902 and has a C_{org}-content of approx. 1.6 %. On average, 52 kg N/hectare are taken up annually. Since the soil has reached equilibrium, this N-uptake has to be considered as input from the atmosphere. This amount corresponds exactly to direct measurements of the atmospheric N-input at this location (Mehlert, 1996, Russow et al., 1995).

Fig. 6 shows the N-uptake of an unfertilized treatment within a 15 year field experiment started in 1984. On average, 170 kg N/hectare are taken up annually. This amount corresponds approximately to the uptake at normal yield level. The long-term results of the Static Fertilization Experiment as well as the experience gathered at this location during the last decades show, that 2.0 to 2.1 % C_{org} in the soil, 0.5 % of which is mineralizable, can be regarded as the optimum on this location. For a crop rotation of sugar beet , spring barley, potato and winter wheat this optimum will be reached by applying 10 t of FYM annually + mineral fertilization. The results of different long term experiments, especially the extended part of the Static Experiment has clearly shown, that the maximum yield will be reached at 2.0 % C_{org} in combination with optimal mineral fertilization.

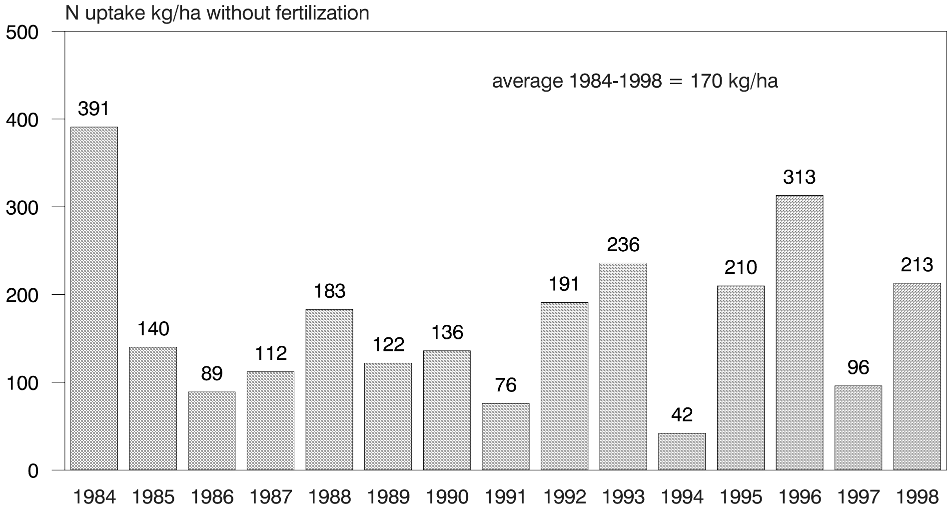

Fig. 6. N uptake without fertilization in a long-term experiment on black earth in Bad Lauchstädt (carried out 1984) in the period 1984 - 1997

Higher applications and the resulting higher C contents in the soil inevitably lead to harmful N-losses and unfavourable C-balances (Körschens, 1997).

An annual application rate of 10 t of FYM per hectare has also been reported as the optimum for the location of Thyrow by Lettau and Ellmer (1997).

N-release depends on the soil's content of mineralizable C (C_m) and the intensity of mineralization, which is 1 1/2 - 2 times higher on sandy soils than on loamy soils. Thus, at the same amount of fertilization, sandy soils have a lower C_m content and, because of their lower clay content, also less C_i.

A "normally" provided soil mineralizes approx. 80 kg of N/hectare on the average of the years. Additionally, an annual N-input of approx. 50 kg/hectare has to be calculated. This has been proved directly by measurements (Russow, et al., 1995) as well as indirectly by the uptake of the unfertilized plots in long-term field experiments, which have reached a flow equilibrium.

N balances

In Fig. 7 the N balances of selected treatments of the Static Fertilization Experiment Bad Lauchstädt are presented. In this case it can be assumed that the experiment has reached the equilibrium and, thus, the input can be compared to the output.

Mineral fertilizer has proved the lowest losses. An optimum management of N fertilization provided a great amount of the atmogenic N input can be used for plant production under the given local conditions. Similar conclusions have been drawn from the results of numerous long-term experiments (Klir et al., 1995; Körschens, 1997; Schnieder, 1990; Weigel et al.,1996)

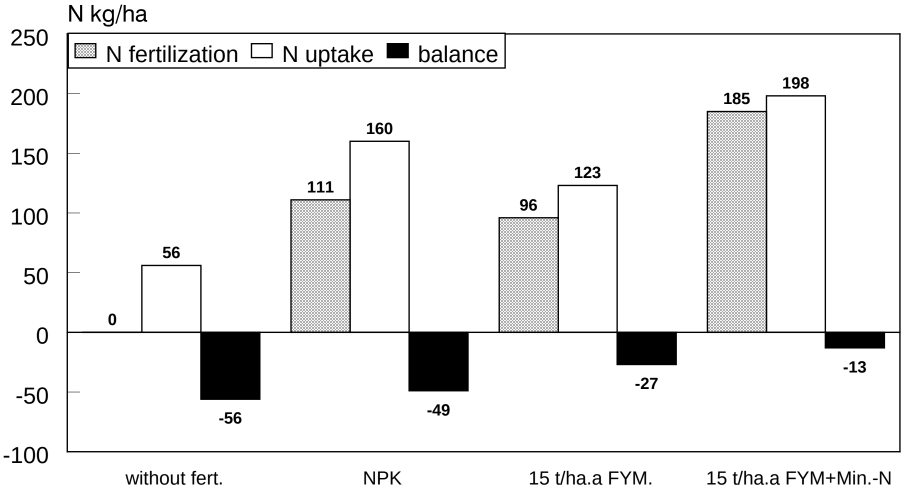

Fig. 7. N balances of selected treatments of the Static Fertilization Experiment Bad Lauchstädt 1968 - 1994

Carbon balance

For the ecological assessment of a farming system carbon is often ignored. However, it is playing a significant role concerning the soil-plant-atmosphere cycle. After all, only the plant is able to bind carbon from the atmosphere by photosynthesis. Thus, every increase in SOM that is not followed by an appropriate increase in plant production, leads to unfavourable C-balances. (example Fig. 8)

Comparing the three variants given in Fig. 9, the exclusive mineral fertilization shows the highest C-increase with 4.33 t/hectare annually. Because of the lower yields, the manure variant shows the most unfavourable results, and also the results of the combined fertilization remain well below the mineral fertilization. (For mineral fertilization a C-input of 1.5 kg per 1 kg N has been used.)

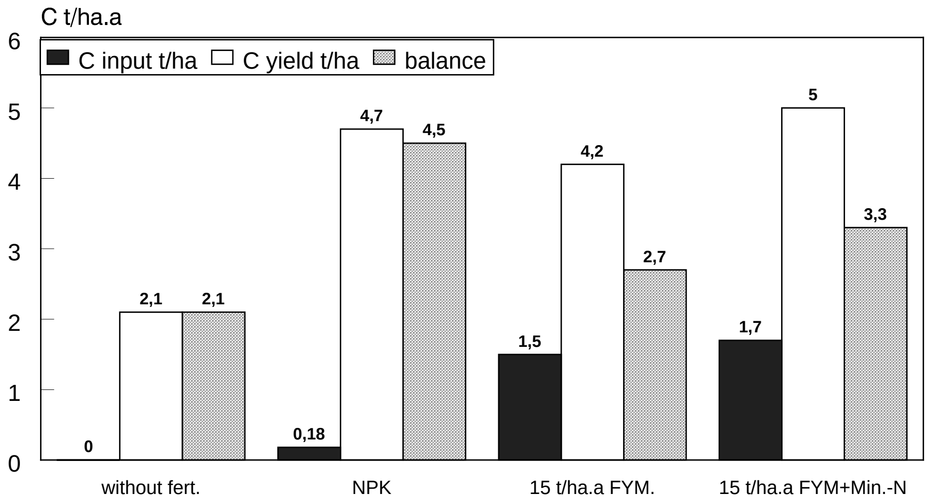

Fig. 8. Carbon balances of selected treatments of the Static Fertilization Experiment Bad Lauchstädt

Carbon and nitrogen dynamics

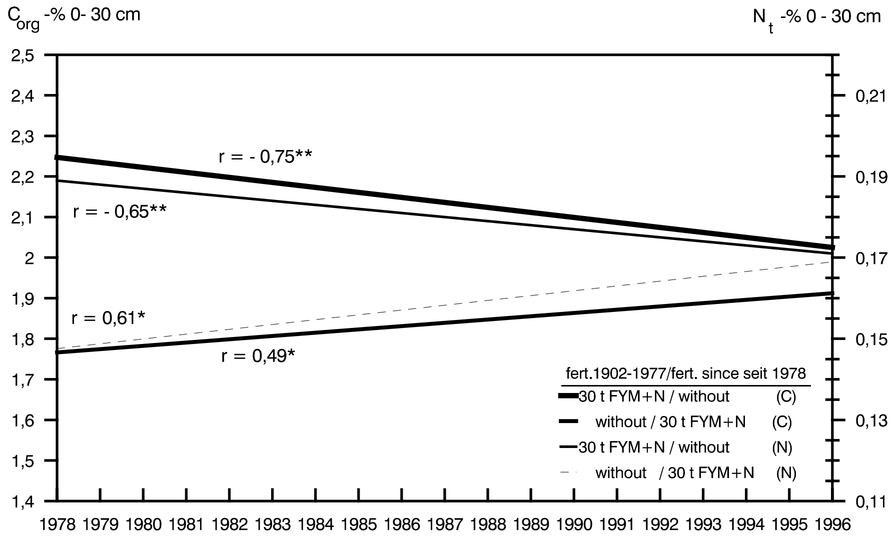

Fig. 9. Carbon and nitrogen dynamics depending on initial level and fertilization in the Static Fertilization Experiment Bad Lauchstädt after extension of experimental question (crop rotation: potato, w. wheat, sugar beet, spring barley)

On the high supply level, i. e. farmyard manure + NPK fertilization from 1902 to 1977, a significant decrease in the C and N content has been observed in the period from 1978 to 1996 reaching up to approx. 40 kg N/ha/a. Thus corresponds very well to the difference in the N uptake which comes up to 37 kg/ha/a .

On the high initial level there has been no change in the soil pool and is not expected either. The difference between „with“ and „nil“ comes up to 46 kg N/ha/a, i. e. on a high supply level - the uptake of manure N is under 50 %.

Fig. 9 shows the changes in the C_{org} and N_t contents as much as their are significant for both characteristics.

It becomes apparent, that only with extreme changes of fertilization, i. e. from „organic-mineral“ to „nil“ or vice versa, significant changes occur after 18 years of experiment. Changes are not yet terminated.

Fig. 10 shows results of an model experiment on the same site. It was initiated 1956 by Ansorge (1966) because the plots were highly differentiated in their initial carbon content (small plot experiment). During the 40 years without any fertilizer C_{org} in the zero treatment since 1902 decreased only slightly and seems to reach with 1.5 % C_{org} its final value and a new equilibrium indicating the inert C_{org} content of this site. Adequately higher are the decreases starting from the higher initial C contents.

Analogous results were found in a long-term experiment in Ultuna (Sweden), where after 30 years a final value of 1.04 % C_{org} was practically reached in the unfertilized bare fallow (Kirchmann et al., 1994).

In a light sandy soil at Thyrow (Germany) the C content of the unfertilized plot, being comparable to a bare fallow because there was no plant growth anymore, was stagnating after 50 years at 0.34 % C_{org} (Schnieder, 1990).

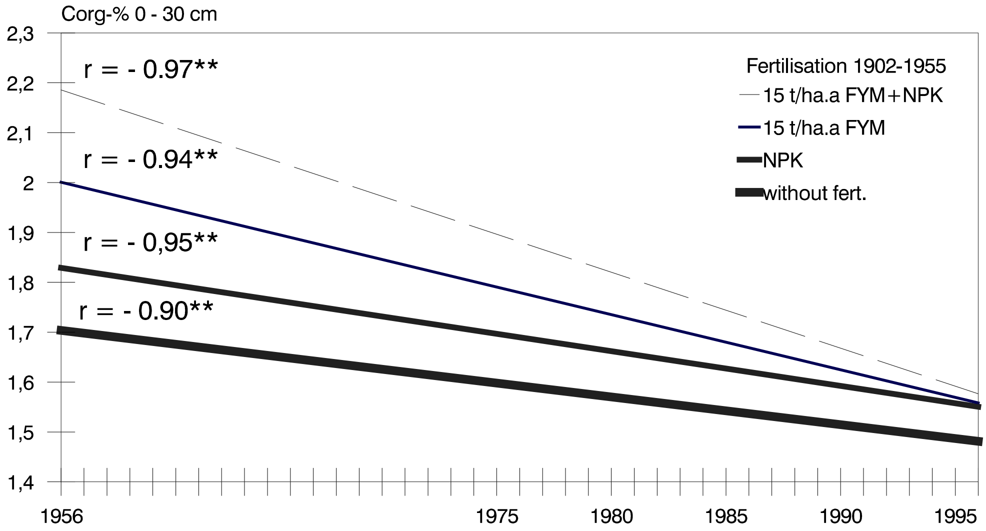

Fig. 10. Changes of C_{org} content in dependence of initial level under bare fallow on Loess Tschernosem without fertilization since 1956

Summary and conclusions

SOM is playing a decisive role in the ecological assessment of farming systems. In the interest of a sustainable development there has to be the demand for high and increasing yields on the one hand and the avoidance of environmental pollution on the other hand. Therefore, yield quantity and yield development are just as much criteria for an ecological and sustainable land use as are nutrient efficiency and C-increase. In practice, an experimental proof is only possible by long-term field-experiments which, in the state of a flow equilibrium, permit the calculation of N- and C-balances without considering soil changes. These changes run very slowly and are, therefore, very difficult to quantify.

The analysis and evaluation of the results of many national and international long-term field-experiments in combination with specific research on the C and N dynamics in the soil in field and model experiments in the location of Bad Lauchstädt leads to the following conclusions:

1. All reflections to soil organic matter require a differentiation into at least 2 fractions:
   - a virtually „inert“ group that is to a large extent uninvolved in mineralisation and
   - dependent of the site conditions.
   - a decomposable group that is mainly influenced by cultivation conditions.
2. High and increasing yields are the aims of a sustainable agricultural soil use with an avoidance of ecological damages
3. The soil improving effect of SOM contributes to crop yield on sandy soils up to 10 %, on loamy soils and up to 5 %.This could be shown by comparing treatments with exclusively mineral fertilisation with those of optimal organic +mineral fertilisation.
4. Highest yields are only attainable on an environmental acceptable way in combination of organic and mineral fertilisation.
5. With a constant management system the Corg content achieves an equilibrium after decades. Changes of this steady state in the soil concern nearly exclusively the decomposable part and proceed very slowly. The direction of the modification depends on the initial level. Same fertilization can cause a decrease in case of a high initial level and an increase in case of a low initial level. In dependency on the starting point more than 50 years can go on up to the achievement of a new equilibrium.
6. The ranges of optimal quantities of carbon and nitrogen in soil are only small. At comparable sites in Germany they are between 0.2 and 0.6 % decomposable carbon and 0.02 and 0.06 % N respectively. Below these values soil fertility, yield and CO2 – absorption by the plant biomass are insufficient, above these values there are losses which could lead to the risk of pollution.
7. The hot water extractable carbon has proved to be an appropriate criterion for the characterisation of the decomposable carbon.
8. When considering the current state of knowledge consistently, the use of mineral fertiliser has a positive influence on the environment and a considerable gain of energy.
9. Too high humus contents can contribute to environmental pollution especially by influencing the C and N balance of the atmosphere as well as by an impairment of the quality of the ground water.
10. The standard values for optimal Corg contents and the „humus balance method“ give the opportunity to control the SOM content of arable soils in such a way to achieve high yields and avoid environmental pollution at the same time.
11. For reproduction of SOM all Primary Organic Matter (POM = roots and harvest residues, FYM, straw, green manure, compost and so on) are suitable in consideration of the stability of their C compounds and the C/N ratio
12. The relation between soil carbon content and physical soil properties is almost functional. An increase of the carbon content by 0.1 % results in:
    - an increase in hygroscopicity of 0.06 to 0.08 mass percent

- an increase in water capacity of 0.4 to 0.6 mass percent
- a decrease of dry matter density of 0.004 to 0.005 g/cm^3
- a decrease of bulk density of 0.006 to 0.008 g/cm^3.

13. Compost is suitable due to the larger stability of its C-compounds to increase the carbon content of sand- and clay soils and to improve thus the soil-physical characteristics.

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NITROGEN DYNAMICS IN COMPOST-AMENDED SYSTEMS

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Introduction

Compost from source-separated organic household wastes and yard trimmings (biowaste compost) is a valuable organic fertilizer and soil conditioner, which supplies the soil with nutrients and organic matter. It also improves soil structure, aggregate stability and water-holding capacity (Vogtmann et al., 1993; Giusquiani et al., 1995; Diez and Krauss, 1997; Wells et al., 2000). The management of biowaste compost for beneficial use in agriculture, however, must take into account strategies to meet crop nutrient needs and protect the environment. Therefore it is necessary to know the availability of nutrients, and particularly of nitrogen from composts. On average, biowaste compost contains 1.55 % N (Zethner et al., 2000). Only a small part of that is present as mineral nitrogen (0.04 % as NO_3-N and 0.01 % as NH_4-N), which is readily available to plants. The greatest part of nitrogen is bound to the organic N-pool, and its availability for plants is low.

Measuring seasonal NO_3-N dynamics in the soil by means of soil samples can serve as an indication of N mineralization, immobilization and leaching. Several field experiments showed soil nitrate-N contents with compost fertilization ranging between those of the unfertilized control and those of mineral fertilized plots. In a trial in Southeast England, municipal solid waste compost was used at two rates (50 and 100 t ha^{-1} fresh matter; f. m.) on a loamy clay soil. While compost treated plots produced grain yields comparable to those which received 75 or 150 kg ha^{-1} mineral N as fertilizer, soil nitrate levels in the compost treated plots were in the same range as those with mineral fertilizers (Rodrigues et al., 1996). Parkinson et al. (1996) applied municipal solid waste and sludge compost and greenwaste compost at rates of 15, 30 and 50 t ha^{-1} (f. m.) on a silty loam soil in Southwest England. Nitrate concentrations in soil samples taken after drilling and during the summer months were not significantly different from the unfertilized control. In a field experiment with broccoli on a Sorrento silty clay loam in California, compost was applied at rates of 0, 22 and 44 t ha^{-1} with and without ammonium nitrate fertilizer. Soil NO_3-N content in the compost plots was not significantly different from the untreated control and soil NO_3-N content in the compost + fertilizer plots did not differ from the fertilizer only plots, while broccoli yield was the same in all treatments (Stamatiadis et al., 1999). The disadvantages of soil sampling are, that it does not give meaningful values during the vegetation period, due to the continuous nitrogen uptake of the plants, and that it provides only snapshot pictures of the soil NO_3-N content, which do not reflect its rapid changes.

For the determination of nitrate leaching, other methods are applied, which cover the nitrate losses more accurately. In the field, nitrate leaching is usually determined by the use of lysimeters or by groundwater analyses, but there are very few lysimeter studies in compost-amended soils. Maynard (1993) measured nitrate in ground water for three years beneath a sandy soil which had been amended yearly with compost at rates of 62 and 124 t ha^{-1}. Nitrate concentrations in ground water from beneath all compost-amended plots remained below 10 ppm during the course of the study. When a total of 119 t ha^{-1} (f. m.) urban compost were applied to a sandy soil in a five year lysimeter study in France, nitrogen leaching amounted to 28 kg ha^{-1} a^{-1}, compared to 11 kg ha^{-1} a^{-1} in the control (Leclerc et al., 1995).

The nitrogen supply during the vegetation period can either be measured directly by analysis of the nitrogen content of the standing biomass or be estimated using indirect parameters, which reflect the nitrogen status of the plants. During the shooting stage of cereals, plant biomass and stem length increase nearly linearly with N-uptake (Reiner et al., 1992; Kübler, 1994). The infection of cereals with mildew *(Erysiphe graminis)* is enhanced by a high nitrogen supply (Kübler, 1994). Therefore, the stem length and the infection rate with mildew provide good indicators of the amount of nitrogen available for the plants.

A different approach leads to the analysis of easily mineralizable nitrogen fractions in the soil. Bronner and Bachler (1979) developed a method using the determination of hot water-soluble nitrogen for the estimation of the potential nitrogen supply of sugar beet fields. Hot water-extracted organic matter is largely composed of carbohydrates and N-containing compounds, in particular amino-N species and amides (Leinweber et al., 1995). The hot-water extract is therefore assumed to contain readily mineralizable organic N, i. e. all forms of N that are likely to be available for plant uptake or transformation processes over the shorter term.

This paper presents results from several field experiments with compost application conducted at the Ludwig Boltzmann-Institute for Biological Agriculture, in which different methods (soil analysis for total N, nitrate-N and hot water-soluble N, plant analysis for total N, analysis of plant growth and disease incidence and measuring of nitrate leaching using lysimeters) were used in order to assess the nitrogen dynamics in these compost-amended systems.

Materials and Methods

The long-term field experiment “STIKO” was set up in the Obere Lobau near Vienna, Austria in the autumn of 1992. Biowaste compost (from source-separated organic household waste and yard trimmings) was applied at 9.5, 17.5 and 25.5 t ha^{-1} a^{-1} (fresh matter; on a ten year mean) respectively, and compared with an untreated control, with three treatments with mineral fertilization (25, 40 and 55 kg N ha^{-1} a^{-1} plus 37 kg ha^{-1} a^{-1} P_2O_5 and 65 kg ha^{-1} a^{-1} K_2O on a ten year mean) and five treatments with combined fertilization. The treatments with combined fertilization did not receive mineral phosphorus or potassium fertilizer. The experiment was set up as a latin rectangle with six replications. The crop rotation included winter rye, potatoes, winter wheat, oats, spelt, early potatoes, winter wheat, winter barley and winter rye. The average composition of the compost used was: 41 % organic matter, 1.21 % total nitrogen, 0.55 % total P_2O_5, 1.00 % total K_2O and a C/N ratio of 24. The soil on the experimental site was a Molli-gleyic Fluvisol (15/62/23 % of sand, silt and clay) with pH 7.6 and a C/N ratio of 9.05.

The soil nitrate-N content was measured three times a year, in early spring, in summer after harvest and in autumn, throughout the experiment (1992 – 2001). Sampling depths were 0 - 30 cm, 30 - 60 cm and 60 - 90 cm. Nitrate was analyzed according to Merck (1986). Contents of total N in the topsoil (0 - 30 cm) were measured in spring 1997 following DIN/ISO 13878 (1998).

In 1996, oat plants were analyzed for their total nitrogen content. Samples of the above-ground biomass were taken six times between mid-May and the harvest in July. In every plot, 32 panicle-bearing stems were harvested and divided into panicle, flag (= leaf 1), the following leaves 2, 3 and 4 and stem. The samples were freeze-dried and analyzed by the Kjeldahl method (Horneck and Miller, 1998). At the same dates, soil samples were taken for the analysis of nitrate-N. The stem length of the oat plants was measured four times in the developmental stages from shooting to anthesis in 1996. In 1995, the infection of the leaves of winter wheat with cereal mildew *(Erysiphe graminis)* was assessed at the end of May (developmental stage : ear emergence) following the classification scheme of Stephan (Mühle and Wetzel, 1990).

In order to assess nitrogen losses to the groundwater, in 1996 a set of lysimeters was installed in three plots with different fertilization (mineral fertilizer, compost, no fertilization) next to the "STIKO" trial. In each of the three plots a lysimeter (with an undisturbed soil column, 1.5 meters high and 1.13 meters in diameter) was installed. After one year without fertilization in order to equilibrate the lysimeters, they were fertilized according to the medium compost and mineral fertilization treatments and the untreated control of the "STIKO" experiment, respectively. Samples were taken from the leachate in the lysimeters at weekly to fortnightly intervals. The parameters analysed in these samples were nitrate, nitrite, ammonium, total nitrogen, total carbon, conductivity, sodium, potassium and chloride. The lysimeters were set up and the samples were taken in cooperation with the Federal Agency for Water Management, Institute for Land and Water Management Research and analyzed by the Federal Environment Agency (Feichtinger and Hartl, 1997).

In the Obere Lobau, a second field experiment, aimed at the evaluation of biowaste compost use at different rates and times was set up in 1992. In this trial, biowaste compost was applied either at 20 t ha^{-1} (f. m.) annually, or at 40 t ha^{-1} (f. m.) every second year, or at 60 t ha^{-1} (f. m.) every third year, or at 60 t ha^{-1} (f. m.) in two consecutive years, or at a single dose of 70 t ha^{-1} (f. m.). The crop was permanent rye. Soil samples taken at the start of the experiment and in autumn 1997 (0 - 30 cm) were analyzed for hot water-soluble nitrogen following VDLUFA (1997).

Further field experiments with compost fertilization were established on several sites in Lower Austria. The composts used were also derived from separately collected organic household waste and yard trimmings.

One experiment was established in 1997 in a Christmas tree plantation on an acidic Cambic Umbrisol, a shallow loamy sand with a pH of 5.9 and a C/N ratio of 14. The compost (C/N ratio: 11.9) was applied at rates of 29 and 58 t ha^{-1} (dry matter) in a single application at the beginning of the experiment. The soil was sampled in spring and in autumn in 0 - 15 cm and 15 - 30 cm depth. Nitrate was analyzed according to Merck (1986). Additionally, the spring samples were analysed for hot water-soluble nitrogen following VDLUFA (1997). For the determination of tree growth, the length of the leader shoot was measured after the end of every growing season.

The second experiment was set up in 1999 in a tree nursery with a moderately humus, acidic, loamy sandy soil with a pH of 4.6 and a C/N ratio of 10.9. Compost rates were 7, 10 and 14 t ha^{-1} (dry matter), applied in a single dose at the start of the experiment. Compost C/N ratio was 10.3. The soil was sampled three times a year in 0 - 15 cm and 15 - 30 cm depth. Nitrate was analyzed according to Merck (1986).

The third experiment was established in an apple orchard in 1997. The soil of the site was a fine sandy silty loam with a pH of 7.5 and a humus content of 2.3 % at the start of the experiment. The compost (C/N ratio: 11.9) was applied at rates of 28 and 56 t ha^{-1} (dry matter) in a single application at the beginning of the experiment. The soil was sampled in spring and in autumn in 0 - 15 cm and 15 - 30 cm depth. Nitrate was analyzed according to Merck (1986). Additionally, samples taken at the start of the experiment and after the first year were analysed for hot water-soluble nitrogen following VDLUFA (1997).

Results and Discussion

In the “STIKO” experiment, total nitrogen concentrations in the soil had risen significantly in the compost treatments after 5 years due to the load of organic matter applied. Total soil N content, however, is not decisive for plant nutrition, as the amount of nitrogen becoming available depends on the mineralization rates of soil and compost. The course of the nitrate-N contents in the soil was similar in all treatments and mainly determined by the crop rotation. Only in the initial phase of compost fertilization the decomposition of the compost in the soil led to a temporary nitrogen fixation, which resulted during short periods in a low nitrogen availability to the crops (Fig. 1).

Averaged over all sampling dates, the nitrate-N content in the main rooting area (0-60 cm soil depth) was 6-14 kg ha^{-1} higher in the compost treatments than in the untreated control. In the mineral fertilized treatments, the difference to the untreated control was in the same range (5-18 kg ha^{-1}). There was no sampling in the first months after mineral fertilization, therefore the short-term effects of mineral fertilization are not included. In the treatments with combined fertilization, the nitrate-N content in the main rooting area was 9-27 kg ha^{-1} higher than in the untreated control. In 60-90 cm depth, where nitrate is prone to leaching, the average nitrate-N contents were also in the same range for compost and mineral fertilized treatments, 1-3 kg ha^{-1} and 0-4 kg ha^{-1} higher than the control. In the combined treatments, the average nitrate-N contents in 60-90 cm depth ranged from 1 to 6 kg ha^{-1}.

Compost and mineral fertilization treatments were also similar regarding the nitrate-N contents of the soil in spring and in autumn. Taking the average over all spring samples, the compost treatments contained in 0-90 cm depth 8-20 kg NO_3-N ha^{-1} more than the untreated control. In the mineral fertilized treatments the difference in spring was 7-19 kg NO_3-N ha^{-1} and in the combined treatments it was 11-36 kg NO_3-N ha^{-1}. Taking the average over all autumn samples, the nitrate-N content in the compost treatments in 0-90 cm depth was 6-21 kg ha^{-1} higher than in the control. In the mineral fertilized treatments, the difference to the untreated control was 4-23 kg ha^{-1}, and in the combined treatments it amounted to 10-38 kg ha^{-1}.

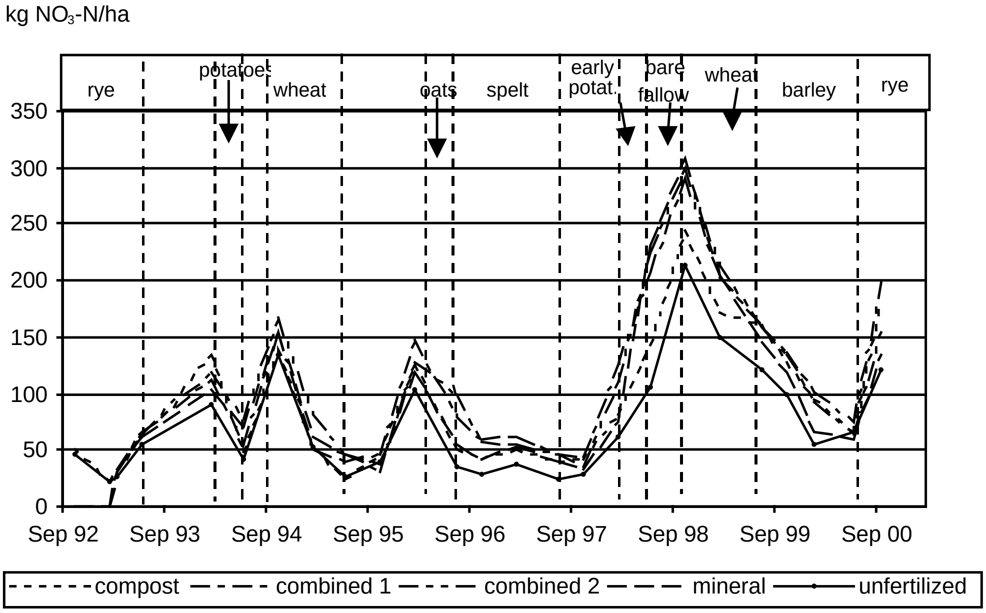

Fig. 1. Nitrate-N in 0-90 cm soil depth

The soil nitrate-N contents showed, that the level of nitrogen supply was slightly raised by compost fertilization. It was just as high as with mineral fertilization following the guidelines for proper fertilization. Even in autumn soil nitrate-N contents were not higher in the compost treatments than in the mineral fertilized treatments. Although total N loads in the compost treatments were much higher than the N loads applied with mineral fertilizer (89 – 226 kg N_{tot} ha^{-1} a^{-1} vs. 25 – 55 kg N_{tot} ha^{-1} a^{-1}; both on a ten year mean), there was no sign of an unbalanced release of nitrogen.

In the experiments in the Christmas tree plantation and in the tree nursery, which are both established on acidic soils, compost application resulted in an increase in soil nitrate-N contents immediately after the application. Three months after the compost fertilization only slightly increased nitrate-N values were measured. In all samples taken later, the nitrate-N contents of the compost treatments did not differ from the unfertilized control, NO_3-N values being lower than 5 kg ha^{-1}.

The nitrate dynamics measured by soil sampling show, that soil NO_3-N content is not more increased by compost fertilization at rates of 9.5 - 25.5 t (f. m.) ha^{-1} a^{-1} than by a moderate mineral fertilization (25 - 55 kg N ha^{-1} a^{-1}). Higher NO_3-N values were only measured immediately after the application of higher compost doses (29 - 58 t d. m. ha^{-1}). These results are in good agreement with the results obtained by Parkinson et al. (1996), Rodrigues et al. (1996) and Stamatiadis et al. (1999).

In the three lysimeters, the courses of the nitrate concentrations in the leachate were very similar in winter 1998/99, after the first year with differential fertilization, and it would be too early to ascribe the small differences in nitrate concentration to the different fertilization regimes. In 2000 very small amounts of leachate were incurred. According to the results obtained up to now, concerns that compost fertilization would increase nitrogen leaching into the groundwater were not confirmed.

Nitrogen concentrations in the oat plants increased steadily and rapidly until 20th June in 1996 (Fig. 2). Plants in the mineral fertilizer or combined fertilizer treatments became saturated or even over-saturated with nitrogen in the shooting phase; plants in the compost treatments were adequately saturated and did not suffer from over-fertilization. Compared to the plants in the treatments with mineral fertilizer or compost application, those in the control clearly took up the least nitrogen. Although nitrogen uptake continued until the time of harvest, no saturation was achieved. Nitrate concentrations in the soil were decisively higher in the compost treatments compared to the untreated control and the mineral fertilized treatments at the beginning of the growing period, prior to mineral fertilizer application. After mineral fertilizer application, nitrate concentrations in the mineral fertilized treatments exceeded all other treatments. Nitrate concentrations in the control were lowest at all sampling dates.

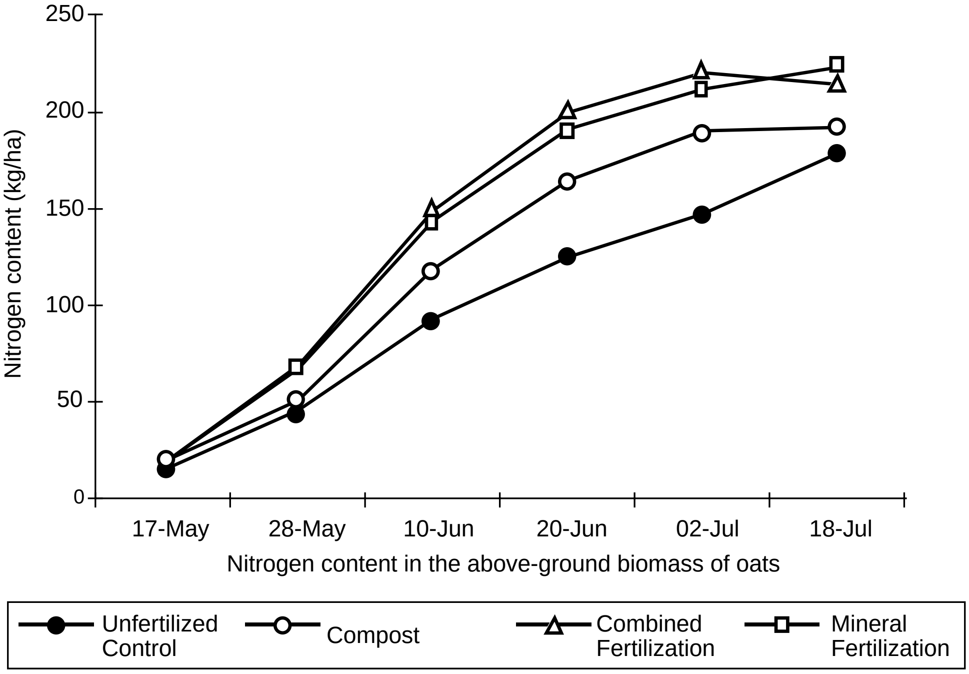

Fig. 2. Nitrogen content in oat plants 1996.

The stem length and the total nitrogen content of the uppermost leaf (leaf 1) of oats showed a very close correlation, corroborating that the stem length is a very sensitive indicator for the availability of nitrogen for the plants (Fig. 3). The unfertilized control showed an average stem length of 79 cm in mid-June, whereas the compost treatments hat stems of 91 – 96 cm length, and the mineral fertilizer treatments had stems of 95 – 100 cm length (Fig. 4).

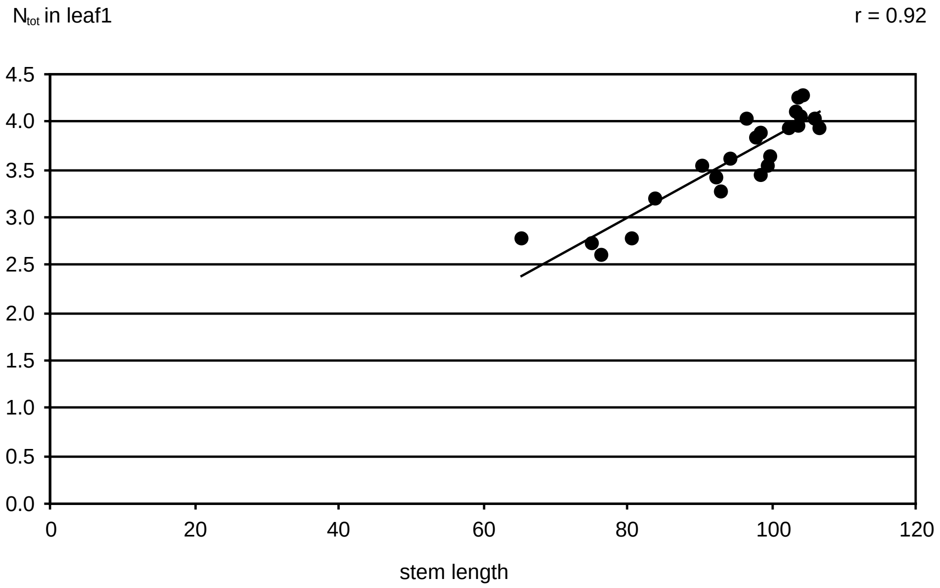

Fig. 3. Correlation between stem length and plant nitrogen content in oats.

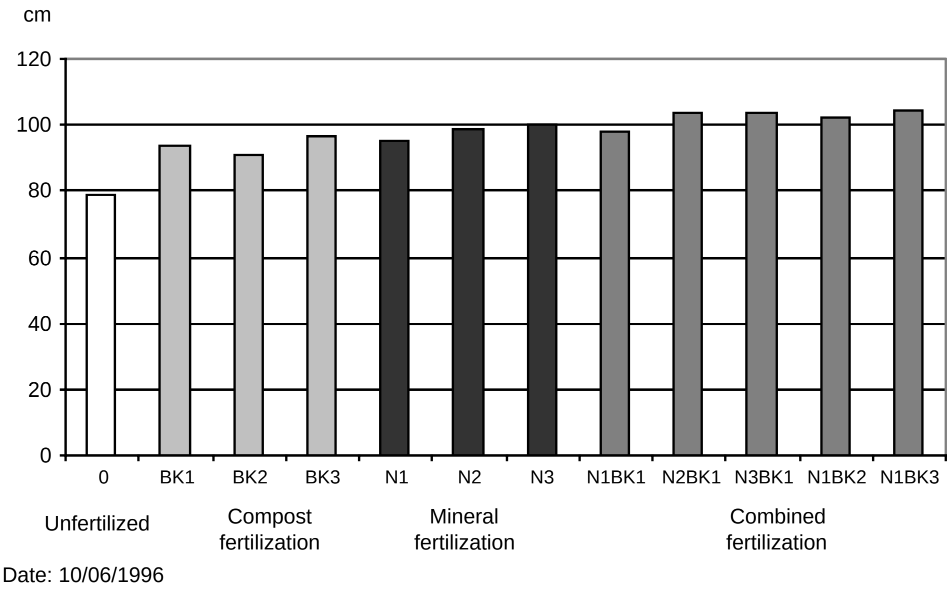

Fig. 4. Stem length of oats.

In the winter wheat of 1995, treatments with a high nitrogen supply, i. e. the treatments with higher mineral fertilization and the combined treatments, were more affected by cereal mildew than the compost treatments (Fig. 5). The average infection rate ranged between 12 % and 40 % in the mineral fertilizer treatments, whereas it was only 5 – 6 % in the compost treatments. The unfertilized control showed an infection rate of 1.5 %. Both of these parameters allowed an estimation of the amount of plant-available N during the vegetation period.

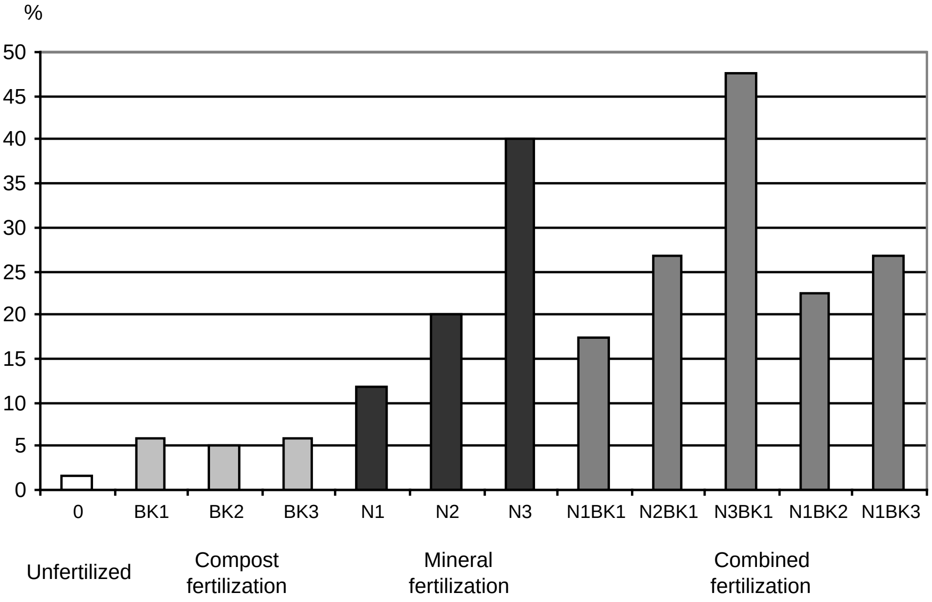

Fig. 5. Infection rate with cereal mildew *(Erysiphe graminis)* in winter wheat.

The soil content of hot water-soluble nitrogen (N_{hws}) was measured in three experiments. In the experiment in the apple orchard, soil N_{hws} amounted to 34 mg kg^{-1} (d. m.) at the start of the experiment. In the compost treatments, it rose for 4 and 9 mg kg^{-1} (Erhart and Hartl, 2000a). In the experiment in the Christmas tree plantation, the soil N_{hws} content was 63 mg kg^{-1} (d. m.) at the start of the experiment. Compost application increased the N_{hws} content for 9 and 18 mg kg^{-1} (d. m.), respectively. In the following years, the content of N_{hws} dropped again (Erhart and Hartl, 2000b). The soil content of N_{hws} was lower in the apple orchard than in the Christmas tree plantation. It did not reflect the fertility of the sites, as characterized by the Austrian soil survey (apple orchard: 53 points, Christmas tree plantation: 21 points). The increase in N_{hws} was more pronounced in the Christmas tree trial, although compost application rates were similar and the same compost was used in both trials. This is in contrast with the effects of the compost application on tree growth and yield. In the apple experiment, yields increased for up to 55 % (Erhart et al., 1999), whereas blue spruce growth was only slightly enhanced. In the apple experiment, the soil N_{hws} content was closely correlated with apple yield (r = 0.76). In the Christmas tree experiment, the correlations were weaker (r = 0.64 in the second year and r = 0.52 in the third year). As the soil in this experiment had a C/N ratio of 14, it seems probable that the N mineralized from the organic matter of the compost was instantly incorporated into the microbial biomass, so that it did not become available for the trees. The hot water-extracted N-containing compounds are largely composed of amino-N species and amides (Leinweber et al., 1995), so they include nitrogen in the microbial biomass.

In the trial with permanent rye, the soil content of N_{hws} was 91 mg kg^{-1} (d. m.) at the start of the experiment, reflecting the high natural fertility of the soil at this site (Hartl et al., 2000). In the unfertilized control, N_{hws} dropped to 81 mg kg^{-1} (d. m.) after four years. In the compost treatments, N_{hws} contents increased by 7 - 14 mg kg^{-1} (d. m.). Soil N_{hws} contents showed only weak correlations with the rye yield and the straw weight (r = 0.50 and r = 0.48).

The increase in soil nitrogen content through compost fertilization was reflected in all three experiments by an increase in N_{hws} concentrations. Compared to the analysis of NO_3-N, which necessarily gives snapshot pictures, the parameter N_{hws} provides additional information on the changes in the potentially mineralizable fraction in the soil. The practical farmer, however, needs a tool to forecast the amounts of nitrogen, which will be mineralized during the growing period. A new, very promising method combines the extraction with neutral salt solution with the use of near infrared spectroscopy (Hartl and Wenzl, 2000).

Conclusion

The contribution of compost to the nitrogen nutrition of crops can be described as well-balanced and is sufficient for the needs of stockless organic farming. For conventional agriculture it provides a basic supply which may be supplemented with reduced amounts of mineral fertilizer if necessary, for obtaining maximum yields.

With compost fertilization in general, but particularly when combining mineral nitrogen fertilizer and compost, the C/N ratio of the compost as well as the site-specific soil C/N ratio should be given some attention. A proper adjustment of the crop rotation, the green manuring measures and the compost fertilization allows to take full advantage of the fertilised nutrients.

Acknowledgements

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COMBINING COMPOST AND SLURRY IN INTENSIVE FLEMISH SILAGE MAIZE PRODUCTION: FATE OF NITROGEN

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Introduction

In Flanders, the selective collection of vegetable, fruit and garden waste (VFG) grew steadily in the past decade. During the year 2000, 375.000 tons of VFG waste were selectively collected and composted, representing an amount of 97 kg per head in regions with selective VFG collection (Anonymous, 2001). It is expected that more regions will adopt the selective collection system in the near future to reduce the organic fraction of household wastes. As a result, the amount of available VFG compost keeps growing. A similar situation occurs in other EU countries (Candinas, 1999). Because other sectors can absorb only limited extra quantities of this VFG compost, agriculture and horticulture are considered potential “markets”. This sounds logic since composting VFG and applying the compost in agriculture completes a loop whereby plant nutrients and organic matter that have been harvested and removed for human consumption are replaced (Diener et al., 1993). A waste becomes a resource (Anonymous, 1976).

However, in order to limit the losses of nitrates from agricultural surface to ground or surface water, the Flemish manure legislation (“Manure Action Plan”, MAP) limits the inputs of nutrients (particularly N) on grassland and arable land (Vlaamse Regering, 2000). For silage maize, the N fertilization limit is 275 kg N ha^{-1} $year^{-1}$ and it is not allowed to supply more than 250 kg N ha^{-1} $year^{-1}$ from organic fertilizers. In the MAP, composts and manures are both treated as organic amendments, differences in N release of both types of organic amendments are not (yet) taken into account. Considering the high stocking density in Flemish agriculture and hence an exuberant availability of manure and slurry, farmers preferentially use the on farm produced organic fertilizers (within the legal limits) on their arable land as well as on their grasslands. Furthermore, little knowledge on the potential advantages of compost in agricultural practice is present. As a result, the farmers’ enthusiasm to welcome VFG compost on Flanders fields is rather low (Anonymous, 2001).

Nevertheless, it has clearly been established that composts protect the soil against erosion (Bazzoffi et al., 1998), enhance the soil water retention (Bengtson and Cornette, 1973; Duggan and Wiles, 1976; Mays et al., 1973), reduce soil compactibility (Bazzoffi et al., 1988), decrease soil acidity (Bengtson and Cornette, 1973; De Haan and Lubbers, 1984; Duggan and Wiles, 1976; Mays et al., 1973), enhance soil biochemical (Giusquiani et al., 1995) and biological activity (Pfotzer and Schüler, 1997) and establish a sound soil ecological equilibrium (Stickelberger, 1977). Additionally, compost has the potential to protect plants from soil (Alvarez, 1995; Coosemans, 1999; Marcos et al., 1995) or seed borne pathogens (Schüler et al., 1993). Hence, compost can be considered as a much-needed soil conditioner (Anonymous, 1976; He et al., 1992) with generally positive crop yield effects (Gallardo-Lara and Nogales, 1987). Only too high doses of urban waste compost (100 Mg ha^{-1}) can lead to toxic amounts of heavy metals in plants (Mays et al., 1973), a possible negative drawback. However, selective collection of the organic fraction of household wastes results in VFG compost, a product with substantially lower contents of heavy metal.

Compost is known to be nutrient rich (Candinas et al., 1999) and the generally high application rates imply a considerable import of nutrients into the soil. Considering the current concern about groundwater contamination, a good knowledge of the availability of especially N in highly matured composts is particularly important (Iglesias-Jimenez and Alvarez, 1993).

The pattern of N availability in highly matured compost is a positive net mineralisation but a partial immobilisation. This is very similar to the pattern of N availability in biologically active soils in which there is a continuous immobilisation of inorganic N into organic phases and a mineralisation of organic N into inorganic forms. This N behaviour is extremely interesting for the conservation of N in agro-ecosystems (Iglesias-Jiménez, 2001). A considerable amount of nitrogen in compost is tied up in an organic form and is released slowly over a period of years (Diener et al., 1993). As a result, a low efficiency of compost-N is observed (Brinton, 1985). Iglesias-Jimenez and Alvarez (1993) demonstrated this limited capacity of municipal waste compost to supply N to ryegrass plants in comparison with mineral fertilizer N. Moreover, because of re-establishing a slow nutrient cycling by fertilizing the soil instead of the plants, the soil becomes resistant against erosion and leaching (Brinton, 1985; Steffen, 1979; Stickelberger, 1977). According to Li et al. (1997), the risk of excessive nitrate leaching only exists at high compost application rates (100 Mg ha^{-1} or more).

If the use of VFG compost on (Flemish) agricultural land has to grow, we should know more about its nutrient supplying capacity (particularly N) and the threats for excessive nitrate losses. We should also know more about the possibilities to combine the use of VFG with the preferentially used manures or slurries.

In Flanders, a yearly application of cattle slurry in silage maize (often grown in a monoculture) with an additional application of mineral N fertilizer is a common practice. The aim of our research was to investigate the possibility of combining an average yearly cattle slurry application (about 40 Mg ha^{-1}) with a moderate yearly VFG compost application (22.5 Mg ha^{-1}). We studied the compost effect on silage maize DM yield and N uptake and we determined the possible saving of additional mineral N owing to the slurry and/or compost application. We also measured the amounts of residual mineral soil N to estimate the possible threats of compost and/or slurry use for excessive nitrate leaching.

Materials and methods

In 1997, we established our experiment on a sandy loam soil of the experimental site of Ghent University at Melle (Belgium, 50°59’ N, 03°49’ E, 11 m above sea level). Some soil fertility parameters at the start of the trial are summarized in Table 1.

Table 1. Soil fertility parameters (expressed on dry soil) on 14 April 1997

	P (mg/100g)*	K (mg/100g)	Ca (mg/100g)	C (%)	N (%)	pH- KCl
Value	32	32	152	1.56	0.126	5.77
Evaluation**	High	Rather high	Normal	Normal		Rather low
Target range**	12 – 18	14 – 20	100 – 240	1.2 – 1.6		6.2 - 6.6

* On dry soil

** According to local reference values for sandy loam soils (Vanongeval et al., 2000)

The trial was established as a block design with three replicates. In 1997, 1998, 1999 and 2000, we applied all possible combinations of the following three fertilization treatments on silage maize:

S: spring application of dairy cattle slurry of on average 42.3 Mg ha^{-1} (S+) or no slurry application (S-)

C: spring application of vegetable, fruit and garden waste (VGF) compost of 22.5 Mg ha^{-1} (C+) or no compost (C-).

M: mineral N fertilization (Ammonium nitrate 27%) of 0, 100 or 200 kg N ha^{-1} year^{-1} (0N, 100N and 200N)

Thus, within each block 12 treatments were applied, each on an individual 54 m² plot.

Table 2 represents the rates of applied compost and slurry and the contents as well as the corresponding amounts of applied nutrients and organic matter ha^{-1}.

Table 2. Applied compost and cattle slurry: rates, composition and applied amounts of nutrients and organic matter (OM).

	VFG Compost					Cattle slurry				
	1997	1998	1999	2000	*Avg./* **Total**	1997	1998	1999	2000	*Avg./* **Total**
Mg ha^{-1}	22.5	22.5	22.5	22.5	*22.5*	51.3	41.3	39.4	37.0	*42.3*
DM (%)	68.9	74.2	66.6	70.6	*70.1*	5.94	6.33	6.45	8.29	*6.75*
C:N ratio	9.0	9.8	11.2	10.7	*10.2*	8.0	7.7	9.0	7.7	*8.1*
Content (% on fresh matter)										
N	1.51	1.59	1.32	1.52	*1.49*	0.29	0.29	0.28	0.49	*0.34*
P	0.30	0.34	0.33	0.31	*0.32*	0.05	0.06	0.05	0.03	*0.05*
K	1.37	1.04	1.10	1.15	*1.17*	0.38	0.33	0.25	0.41	*0.34*
OM	23.9	28.7	27.5	29.5	*27.4*	4.66	4.40	5.04	6.24	*5.09*
Applied (kg ha^{-1})										
OM	5378	6458	6188	6638	**24660**	2389	1817	1985	2308	**8499**
N	340	358	297	342	**1337**	150	118	110	181	**559**
P	68	77	74	70	**288**	28	24	20	12	**83**
K	308	234	248	259	**1049**	199	136	99	150	**584**

We applied the slurry on half of each block (in split-plot) about a week before sowing the silage maize. The surface spreading was immediately followed by incorporation with a cultivator. Two to three days later, the soil was ploughed. On the plots receiving no slurry, a mineral fertilization of 33 kg P (triple super phosphate) and 208 kg K (muriate of potash, 40%) ha^{-1} was applied after the ploughing. The VFG compost was also spread after the ploughing, about two days before the sowing of the silage maize. This compost as well as the additional mineral N fertilization (100N or 200N) were applied manually and incorporated with a rotary harrow, when preparing the seed bed. The maize was then sown at 104.000 kernels ha^{-1}, the inter-row distance being 0.75 m. The sowing dates were 24 April 1997, 14 May 1998, 12 May 1999 and 8 May 2000.

At the end of the growing seasons, the maize DM yields were determined on the central 6m² of each individual plot. The harvesting dates were 22 September 1997, 2 October 1998, 22 September 1999 and 3 October 2000.

The plant parts (leaves and stalks) and the ears were weighed separately. The plant parts were chopped and dried (for 12 hrs at 80°C), the ears were dried unchopped (for 12 hrs at 80°C, then for 4 hrs at 105°C). The N-content of the dried maize samples was determined (Kjeldahl method) and the N taken up by the harvested silage maize was calculated by multiplying DM yields and corresponding N contents. For each of the combinations of slurry and manure application (S- C-, S- C+, S+ C- and S+ C+), a quadratic curve was fitted to express the yield response to the amount of applied mineral N fertilization. The economical optimum of additional mineral N fertilization (N_{opt}) was considered to be reached when the first derivative of this curve (the marginal yield response) dropped below the cost/ value ratio (Neeteson and Wadman, 1987). The latter is the ratio of the cost of 1 kg of mineral fertilizer N to the purchase price of 1 kg DM of crop yield (silage maize). In Flemish agricultural practice conditions, this resulted in:

$$\text{Cost Value ratio (cvr)} = \frac{\text{Cost of 1 kg of mineral fertilizer N}}{\text{Purchase price of 1 kg of DM yield}} = \frac{0.75 \text{ Euro}}{0.075 \text{ Euro}} = 10$$

In order to evaluate the release and the use of the compost and/or slurry N, we used three methods:

1) We determined the N_{opt} for the four main treatments (S-C-, S+ C-, S- C+ and S+ C+). The difference between the N_{opt} of the S- C- system and the N_{opt} of an organic fertilization was considered the useful amount of N (“N credit”) of this organic fertilization (Paré et al., 1993). The found N_{opt} and the N credit are valuable parameters for practice and fertilization advisory systems and we related it to the total organic N applied. We used this ratio as a measure of the efficiency of the applied compost-, slurry- or compost + slurry-N:

   $N_{eff}\,(\%) = 100 * Ncredit / F = (N_{opt}\,control - N_{opt}\,T) / F$

   With N_{opt} control = economical optimum mineral N fertilization of the S- C- treatment; N_{opt} T = economical optimum mineral N fertilization of the considered organic fertilization; F = total N applied with the considered organic fertilization (S+ C-, S- C+ or S+ C+).

2) To situate our results in the state of the art concerning compost N availability, we calculated the apparent N use efficiency (ANUE), a parameter often cited in literature and defined as:

   $ANUE\,(\%) = 100 * (N_F - N_S)/F$

   Hereby, N_F = N uptake of silage maize; N_S = N derived from the soil N reserve, assumed to be equal to the N uptake by the control (S- C- 0N) (Greenwood et al., 1987) and F = total N applied with the organic fertilization.

3) The global N efficiency of each applied fertilization combination of slurry, compost and mineral N was determined by expressing the total maize N uptake as a percentage of the total fertilization N input, organic as well as mineral (Poudel et al., 2001).

At the end of the growing season, we sampled the soil for analysis of mineral N content. Using a gauge auger, 4 at random spots were sampled on each plot; a bulked sample was composed per treatment, separately for the horizons of 0 to 30, 30 to 60 and 60 to 90 cm of soil depth. We extracted the samples with a 1% $KAl(SO4)_2$-solution; nitrate was then measured using a nitrate-specific electrode. The amount of residual soil nitrate-N in the soil profile was compared to the target value adopted in Flemish manure legislation: the amount of residual nitrate-N measured between 1 October and 15 November in the soil profile up to 90 cm should not exceed 90 kg ha^{-1}.

We sampled the soil on 7 October 1997, 22 October 1998, 10 November 1999 and 9 November 2000. On this last date we also sampled the 0 – 30 cm profile for analysis of carbon (Walkley and Black method) and total N (Kjeldahl method) content.

The precipitation and average air temperature measured at Melle, values for the experimental years as well as the long-term averages (1962 – 2000), are summarized in Table 3.

Table 3. Precipitation (l m^{-2}) and average air temperature (°C) at Melle. Measurements during the experiment and the long-term average (1962 – 2000, "Norm")

	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	Total
Precipitation													
1997	8.8	69.0	28.3	19.8	93.6	114.1	74.9	39.6	26.4	108.6	56.2	102.6	636.5
1998	77.7	12.4	73.9	95.2	27.8	123.0	47.6	67.8	136.1	106.5	144.7	82.0	742.7
1999	104.0	51.3	82.0	72.1	38.3	71.9	34.3	131.7	46.8	66.6	41.5	184.6	661.8
2000	44.1	81.3	62.7	59.2	87.9	43.5	201.3	64.4	97.0	124.7	93.8	86.6	741.6
Norm	60.2	46.1	59.9	48.5	60.2	75.3	71.8	62.1	64.3	72.2	75.8	71.8	808.3
Average air temperature													
1997	-0.7	6.6	8.6	7.9	12.7	16.0	17.1	20.2	13.9	9.9	7.1	5.2	
1998	4.6	6.0	7.6	9.4	14.9	16.4	16.5	16.7	15.5	9.9	3.9	5.1	
1999	5.8	3.5	7.3	10.1	14.5	15.1	17.4	18.9	17.4	10.9	6.3	4.8	
2000	4.3	5.9	7.1	10.0	14.8	16.3	15.8	17.9	16.3	11.6	8.0	5.7	
Norm	2.4	3.1	5.2	8.4	12.1	15.1	16.8	16.7	14.4	10.3	6.2	3.2	

Results and discussion

Soil, compost and slurry features

Our sandy loam soil was quite rich in P and K (Table 1); we could consider these nutrients not to be limiting for crop growth and yield. Frequent application of slurry or manure in the past kept the soil carbon content at a level of 1.56%, fitting within the target range for this type of soil.

The used VFG compost had a total N content of on average 1.49% on fresh weight. This is a rather high value when compared to literature references (He et al., 1992; He et al., 1995; Kuhn et al., 1996) and local Flemish reference values of 0.9 to 1.4% of total N on fresh weight (De Vliegher, 2001). The high N content of the fresh compost was also due to the high DM content of the compost (on average 70 %). The organic matter content (on average 27.4% on fresh weight) was within the local reference values of respectively 20 to 32 % on fresh weight. Table 2 illustrates the large amounts of organic matter input, typical for compost application (He et al., 1995; 2000).

Compared to the VFG compost, the cattle slurry contained considerably less OM and total N, the applied amounts of OM and N were respectively 34 and 42% of those applied with compost.

Also the C : N ratio of the applied compost (on average 10.2) was within the reference range of 9 to 15 and hence well below 20, which should exclude negative yield effects owing to high N immobilization (Bazzoffi et al., 1998; Eriksen et al., 1999).

Silage maize dry matter yields

The dry matter yields of the silage maize are represented in Table 4. The 1997 yield was highest owing to good water availability during spring and during the warm summer months (Table 3). 1998 was the least favourable season with an excessive precipitation during early spring, a very dry month of July and again abundant precipitation from the end of August.

Despite reports on limited experienced effects of compost rates of less than 38 Mg ha^{-1} (Duggan, 1973), our yearly application of 22.5 Mg VFG compost ha^{-1} had a significantly positive effect on the attained silage maize yields. Without the use of slurry, the compost effect on DM yield during the first season following application was not significant. This is in accordance with the findings of Sullivan et al. (1998). On average over the four year period however, the benefit owing to the VFG compost was 9.0, 4.5 and 0.2% at additional mineral N fertilization levels of respectively 0, 100 and 200 kg N ha^{-1}.

Table 4. Silage maize dry matter yields (Mg ha^{-1}) with (S+) or without (S-) slurry application, with (C+) or without (C-) compost application and with 0, 100 or 200 kg mineral N ha^{-1} (resp. 0N, 100N and 200N)

	S +						Statistical signific.[a]		
	C -			C +			C	N	C X N
	0N	100N	200N	0N	100N	200N			
1997	20.7	21.4	21.7	21.6	23.2	23.7	***	***	NS
1998	15.8	17.3	17.5	17.1	18.0	18.0	***	***	NS
1999	18.4	19.5	19.8	20.0	19.9	20.6	*	NS	NS
2000	18.6	18.7	19.2	19.6	19.2	19.2	NS	NS	NS
Average	18.4	19.2	19.5	19.6	20.1	20.4	***	***	NS
	S -								
	C -			C +					
	0N	100N	200N	0N	100N	200N			
1997	19.1	21.6	22.5	19.4	22.5	21.7	NS	***	NS
1998	13.6	17.0	17.5	15.1	17.7	18.4	***	***	NS
1999	15.4	18.5	19.9	17.4	20.1	20.4	***	***	NS
2000	13.8	18.4	19.2	15.5	18.5	18.9	NS	***	*
Average	15.5	18.9	19.8	16.8	19.7	19.8	***	***	**

[a] *** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; NS = not significant

Novahedi Naeni and Cook (2000) found comparable relative yield benefits following the application of 50 Mg ha^{-1} of domestic waste compost: 7.0 to 11.2% and 2.5 % at additional mineral N fertilization levels of respectively 0 and 100 kg N ha^{-1}. Higher corn grain yield benefits (+64% and +16% at 0 and 91 kg of additional mineral fertilizer N ha^{-1}) were obtained with only 20 Mg compost ha^{-1}, but these results were obtained on a very poor loam soil (Duggan and Wiles, 1976).

When we applied slurry, the yield benefit owing to compost was still 6.3, 4.6 and 4.3 % respectively at additional mineral N fertilizer levels of 0, 100 and 200 kg N ha^{-1}. In the latter case, the continuous positive effect at the highest dose of mineral N fertilization indicates that the positive yield effect of the compost was not a mere N contribution effect. This is in contradiction with de Kok (1996) and de Haan and Lubbers (1984), who conclude that positive crop yield effects owing to compost were to be explained as merely nitrogen effects and that there were no compost yield effects that could not be obtained with additional mineral fertilizer. De Kok (1996) also stated that yield effects of VFG compost are not to be expected when the VFG effective nutrient import is taken into account when applying mineral fertilizers. From another point of view: with compost application, the same crop yields can be obtained with less additional mineral fertilizer. This was clearly illustrated by the calculated levels of economical optimum additional mineral N fertilization (Table 5).

Table 5. Economical optimum amount of additional mineral fertilizer N (kg N ha^{-1}) and the corresponding yield (kg DM ha^{-1}) on plots with (S+) or without (S-) slurry application and with (C+) or without (C-) compost application

	1997	1998	1999	2000	Average
N_{OPT}					
S- C-	146	135	164	146	148
S- C+	103	135	138	124	125
S+ C-	62	64	79	20	56
S+ C+	94	43	22	12	43
YIELD AT N_{OPT}					
S- C-	22306	17487	19782	19275	19713
S- C+	22561	18125	20662	18860	20052
S+ C-	21445	17022	19421	18879	19192
S+ C+	23133	16679	20508	19712	20258

Economical optimum mineral N fertilization (N_{opt})

Compared with the plots receiving only mineral fertilizer N, silage maize on plots with compost application needed 0 to 43 kg less mineral fertilizer N ha^{-1} to reach optimum yields (Table 5). Kuhn et al. (1996) state that in the first growing season following application, only 10% of the total amount of applied compost N can be subtracted from fertilization. Heller (1999) concluded that less than 40 kg N ha^{-1} of plant available N was released in the first vegetation period following the application of 25 ton DM of compost ha^{-1}. Our results seem consistent with those findings, when we consider a system without slurry application. The rather small N credit of compost is a first indication that the release of nitrogen from the VFG compost is limited, compared to the large amount of N applied with it (Table 2). Van Erp et al. (1997) and Eriksen et al. (1999) stated that the small amount of released N from VFG compost implies the need of additional mineral fertilizers to obtain optimal crop growth and yields. Indeed, also in our experiment, we still needed additions of 103 to 138 kg mineral N ha^{-1} to reach optimum yields on plots with VFG compost application.

Slurry application (S+ C-) decreased the necessary amount of mineral fertilizer N more substantially: compared to the S- C- treatment, a N credit of 84 to 126 kg N ha^{-1} was found, resulting in necessary additions of 20 to 79 kg N ha^{-1}.

When slurry was applied, the addition of compost increased the optimum amount of additional mineral N from 62 (S+ C-) to 94 kg N ha^{-1} (S+ C+) during the first growing season following

VFG compost application. During the following years however, the combination of slurry and compost decreased the need for additional mineral N steadily to a level of only 12 kg N ha^{-1} in 2000. Compared with mineral N fertilization (S- C-), the combination of slurry and compost enabled to save 52 (in 1997) and even 142 kg mineral N ha^{-1} (in 2000) without putting DM yields at risk.

We remark that the DM yields at the N$_{opt}$ fertilization levels were comparable for all treatments; although a slight average benefit for the treatments with compost application (C+) was observed.

Silage maize N uptake and N content

Table 6 summarizes the N uptake by the silage maize plants and illustrates that compared to the S-C- treatments, the maize took up 17.4, 12.9 and 0.9% more N when compost had been applied, with additional mineral N fertilizer of 0, 100 and 200 kg N ha^{-1}. This higher uptake goes along with the higher yields, mentioned above (3.2.) but the relative benefits are higher. This indicates that also the silage maize N content is higher in the S – C+ compared to the S -C- silage maize. This higher N content is most definite at 0 and 100 kg of additional mineral N fertilizer (Fig. 1). Slurry shows this N concentration effect even more pronounced. Combining slurry and compost results in the highest N uptake, owing to a combination of the highest yields (Table 4) and the highest N contents (Fig. 1). Only at the highest mineral N rate of 200 kg N ha^{-1}, the differences in N content are negligible.

Iglesias-Jiménez (2001) also observed significantly higher N contents of barley grown on soils with city refuse compost amendment (60 Mg ha^{-1}) compared with a control soil: 1.58 versus 1.08 % in control treatment. Duggan and Wiles (1976) found higher N contents in the ear leaf of maize plants growing on soils with a compost amendment of 20 Mg ha^{-1}: 1.77% compared to 1.12 in a control treatment. When additionally 182 kg N ha^{-1} were applied these values also converged to comparable values of respectively 2.40 and 2.45 %.

Table 6. Silage maize N uptake (kg N ha^{-1}) with (S+) / without (S-) slurry, with (C+) / without (C-) compost, with 0 (0N), 100 (100N) or 200 (200N) kg ha^{-1} mineral N application

	S +						Statistical signific.[a]		
	C -			C +			C	N	C X N
	0N	100N	200N	0N	100N	200N			
1997	197	204	231	219	247	251	***	***	**
1998	145	187	189	165	196	200	***	***	NS
1999	148	205	213	193	211	234	***	***	*
2000	197	213	220	210	201	215	NS	*	*
Average	172	202	213	197	214	225	***	***	**
	S -								
	C -			C +					
	0N	100N	200N	0N	100N	200N			
1997	161	208	241	148	211	222	**	***	*
1998	115	171	187	133	180	199	***	***	NS
1999	100	166	211	138	219	232	***	***	**
2000	91	184	209	130	213	204	***	***	***
Average	117	182	212	137	206	214	***	***	***

[a] *** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; NS = not significant

Efficiency of compost and slurry N

The N efficiency (N_{eff}) of the slurry-, compost- and slurry + compost-N, calculated as the found N credit (derived from the N_{opt} values in Table 5) related to the total amount of applied organic N (Table 2), are represented in Table 7.

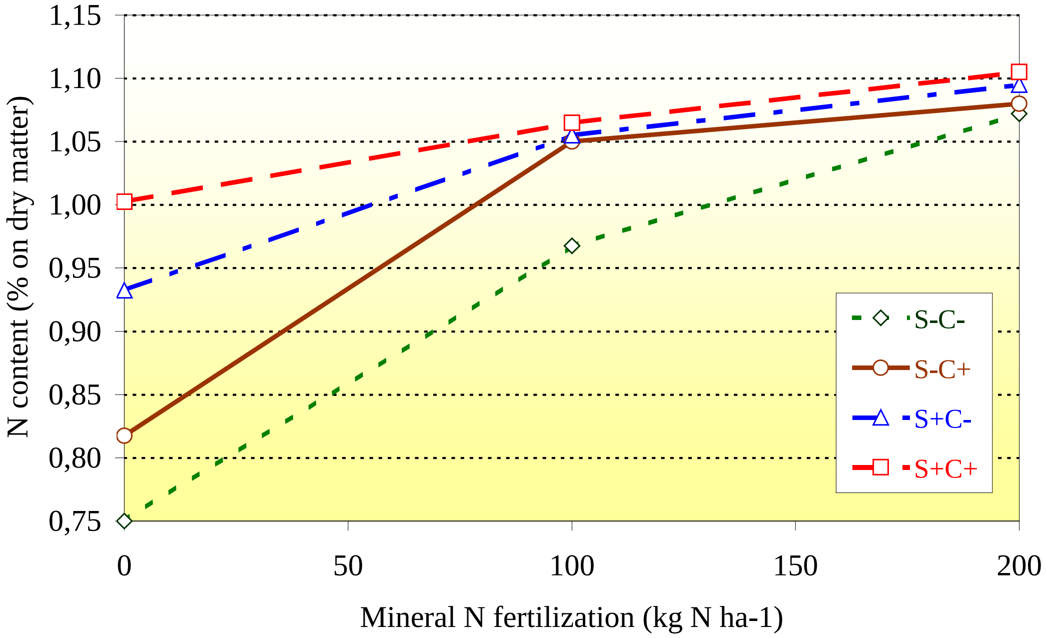

Fig. 1. Average N content of the silage maize plants at harvest (S -: no slurry; S+: slurry; C- : no compost; C+: compost)

Table 7. Efficiency of the N applied with compost, slurry or compost + slurry (N_{eff}, %)

	1997	1998	1999	2000	Average
Compost (S- C+)	12.6	0.0	8.8	6.4	6.9
Slurry (S+ C-)	56.0	60.2	77.3	69.6	65.8
Compost+slurry (S+ C+)	10.6	19.3	34.8	25.6	22.1

Table 8. Apparent N use efficiencies (ANUE, %) in silage maize with compost, slurry or compost + slurry application

	1997	1998	1999	2000	Average
Compost (S- C+)	-3.9	5.1	12.6	11.5	6.1
Slurry (S+ C-)	23.5	25.3	43.7	58.7	39.3
Compost+slurry (S+ C+)	11.7	10.5	22.8	22.7	16.8

It is obvious that the compost-N is substantially less efficient compared to slurry-N: on average over the first four trial years, only 6.9% of the applied amount of N is found as useful N (which means that this amount can be subtracted from the economic optimum amount of mineral N fertilization). In terms of ANUE, a comparable average value of 6.1% was found (Table 8). This observed ANUE on the compost plots corresponds quite well with values cited in literature: 9.2% (composted manure, Brinton, 1985) 9.5 to 11.2% (20 to 30 Mg compost ha^{-1}, Iglesias-Jimenez and Alvarez,1993), 8% (50 Mg compost ha^{-1}, Mamo et al, 1998), 5% (composted manure, 38 Mg ha^{-1}, Paul and Beauchamp,1993), 14% (composted manure, 52 Mg ha^{-1}, Eghball and Power, 1999). These findings illustrate the slow rate of release of N from compost, this rate being generally much less than in the original organic by-product (Sikora and Szmidt, 2000), in our case the vegetable, fruit and garden waste (VFG).

Hadas and Portnoy (1994) found a net mineralization rate of the compost insoluble N of maximum 10% for composted manure. This is in accordance with De Neve and Hofman (1997) and Sullivan et al. (1998) who found that, in vitro mineralisation of N from VFG compost was respectively 10.4 to 16.1 % of the organic N and 10.6% of the total N.

Diez and Krauss (1997) highlighted that the amount of compost-N found in the crop yield increased from 16% during the first three years to approximately 40% after 20 years of a yearly application of 15 Mg compost ha^{-1}. This 40% results from accumulated after effects of the compost applied during the preceding years.

In contrast, according to Van Erp et al. (1997), also the N after effect is rather limited and N fertilization of the crops doesn’t need much correction. In our system without slurry application, our results confirm this statement (Table 5).

Van Erp et al. (1997) add that only on the long-term, soil organic matter will increase and so will the mineralization capacity.

The found N_{eff} (on average 65.8%) and ANUE (on average 39.3%) values of slurry were considerably higher than the ones of compost, illustrating the higher release of N from this organic source of N. The combination of slurry and compost resulted in average N_{eff} and ANUE values of respectively 22.1 and 16.8%. In this S+ C+ system, the increasing Neff and ANUE and the resulting decrease in optimum amount of additional mineral N (Table5) reflect an apparent increase in N release with time.

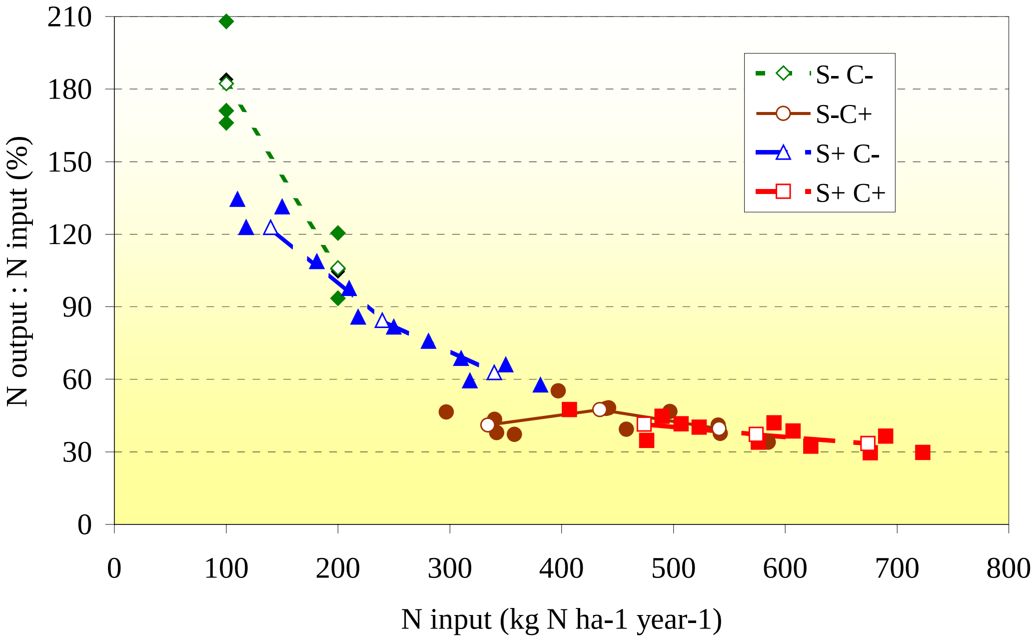

Fig. 2. N output : Ninput ratio in the silage maize crops (S -: no slurry; S+:slurry; C- : no compost; C+: compost) Black markers represent the yearly values; white markers and lines represent the average (1997 to 2000).

The ratio of total N input (from fertilizer) to N output (N uptake by aboveground silage maize parts) is clearly lower in the systems with the highest N input, corresponding with the S-C+ and S+ C+ treatments (Fig. 2). Only about 40% of the applied N is found in the plant N uptake. This apparent low efficiency of N use could indicate excessive N losses. In Flanders, a major concern is to reduce the nitrate leaching. The parameter to quantify the risk of nitrate-N leaching is the amount of residual mineral soil nitrate-N at the end of the growing season.

Residual mineral soil N

The end-of-season amounts of residual soil N (Fig. 3) are the lowest for the S-C- treatments, they increase over the S+ C- and S- C+ to reach the highest values for the S+ C+ treatments. Increasing the additional amount of mineral N fertilizer increases the residual soil N substantially for each of the organic fertilizer treatments.

Table 9 illustrates that relative to the total amount of applied N, the increase in end-of-season residual soil nitrate N is the smallest with applications of compost and compost + slurry. Thus the low global efficiency of these systems (ratio Nout : Nin, Fig. 2) is not reflected in a higher proportion of left unused in the soil profile and hence prone to over winter leaching.

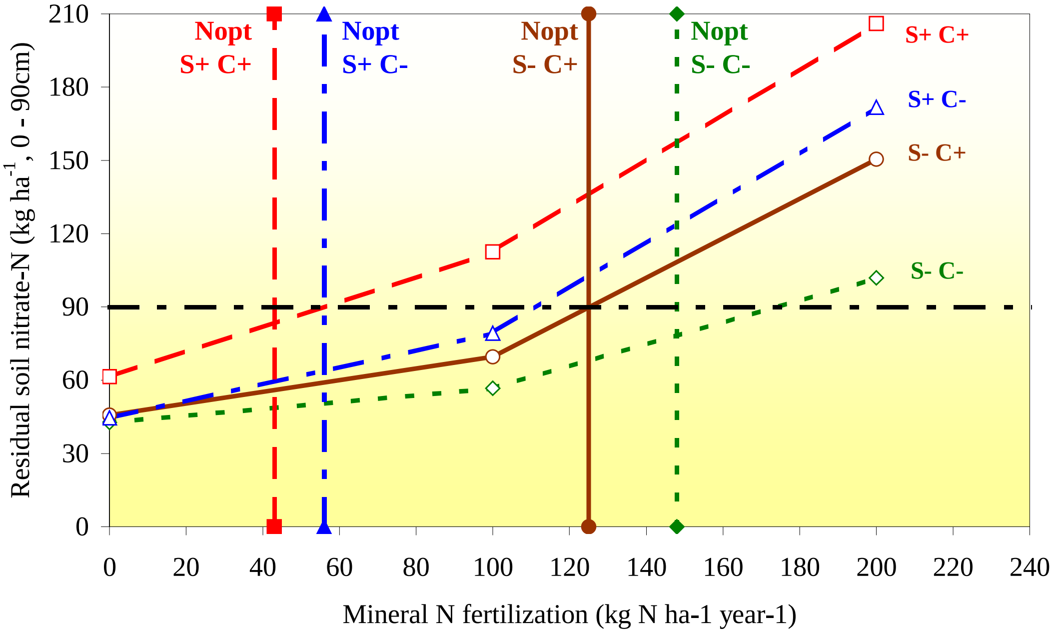

Fig. 3. Average (1997 to 2000) residual soil nitrate N and economically optimum mineral N fertilization (Nopt) of the organic fertilization treatments (S-: no slurry; S+:slurry; C- : no compost; C+: compost).

We observed that on average, the limit of 90 kg N ha^{-1} was not trespassed when an additional mineral N fertilization of no more than N_{opt} was applied (Fig. 3). Under this precondition, also the compost or slurry + compost system, in which we observed a large surplus of the N balance, do not cause an immediate threat for excessive amounts of residual soil N and hence large potential over winter nitrate losses.

Also Van Erp et al. (1997) suggested that the use of VFG compost has no influence on the height of the post harvest residual mineral soil N and hence does not increase the risk on nitrate leaching during winter. We can only agree with this statement if we add that the amount of additional mineral N was adapted.

Iglesias-Jiménez (2001) concluded that city refuse compost cannot be considered as a poor-release N material when it has a high degree of maturity but that nitrate leaching and pollution of the ground water only occur when high doses of this compost are applied (>50 Mg ha^{-1}) (Mamo et al., 1999). This was confirmed by Li et al. (1997) and Mamo et al. (1999). De Kok (1996) stated that even following 20 years of VFG application (22 Mg ha^{-1}, once every two years) the resulting extra mineralisation would only be approximately 60 kg N ha^{-1}year^{-1} and that the potential environmental threat (nitrate leaching) would be small.

Table 9. Increases in soil residual nitrate-N compared with the S- C- ON plots (values in bold): absolute values (kg NO_3-N ha^{-1}) and values relative to the total N input (%). With (S+) or without (S-) slurry application, with (C+) or without (C-) compost application and with 0, 100 or 200 kg N of mineral fertilization ha^{-1} (resp. 0N, 100N and 200N)

	S- C-	S-C-		S+C-			S-C+			S+C+		
	0N	100N	200N	0N	100N	200N	0N	100N	200N	0N	100N	200
Absolute												
1997	**59**	9	9	12	37	127	-3	15	67	10	48	155
1998	**35**	26	66	8	56	126	1	32	86	30	82	123
1999	**39**	3	144	13	46	223	16	54	216	33	98	185
2000	**38**	17	17	-2	9	41	-2	7	63	2	52	190
Average	**43**	14	59	2	37	129	3	27	108	19	70	163
Relative												
1997		9	5	-8	15	36	-1	3	12	2	8	22
1998		26	33	6	26	40	0	7	15	6	14	18
1999		3	72	12	22	72	6	14	43	8	19	31
2000		17	9	-1	3	11	-1	2	12	0	8	26
Average		14	30	1	15	38	1	6	20	4	12	24

Storage of C and N in the soil

A significant soil storage of organic matter and N in fertilization systems including compost application may explain why the global N efficiency of Fig. 1 doesn't lead to excessive increases in N losses, particularly in higher over winter nitrate leaching.

After four years of compost application, we already observed a significantly higher soil C ($P < 0.01$) and N content ($P < 0.001$) on plots with compost application (Table 10). Corrected for the decrease on the S- C- plots, the amounts of C and N in the top 30cm of soil increased with respectively 4500 to 4950 kg and 495 to 540 kg ha^{-1}. De Kok (1996) stated that the organic matter content of the soil can be kept stable by regular application of VFG compost, on the long term it even can be enhanced.

The soil C and N contents on the S - and the S+ plots were not significantly different in November 2000. The amount of applied slurry organic matter compensated the decrease (mineralisation) of available organic matter at the start of the experiment and brought only very few additional C and N into the soil.

Table 10. C content and nitrogen content (% on dry soil) at the start of the experiment (1997) and in November 2000. November 2000 storage of C and N (kg ha-1) relative to 1997. Plots with (S+) or without (S-) slurry application, with (C+) or without (C-) compost application.

	1997	November 2000			
		C-		C+	
		S+	S-	S+	S-
Content					
C	1,56	1,58	1,54	1,64	1,65
N	0,126	0,121	0,116	0,127	0,128
Storage					
C		1800	-900	4500	4950
N		225	-450	495	540

Conclusions

In a silage maize monoculture on a sandy loam soil, an average yearly application of 22,5 Mg of vegetable, fruit and garden waste compost ha^{-1}, in addition to 42 Mg of cattle slurry ha^{-1} resulted in economical optimum DM yields with a substantial saving of mineral fertilizer N. During the first, second, third and fourth year of this compost + slurry application, an additional amount of mineral fertilizer N of respectively 94, 43, 22 and 12 kg N ha^{-1} was needed. Compared to a system with only mineral N fertilization, this implied savings of respectively 52, 92, 142 and 134 kg N ha^{-1}.

Maize N uptake as well as N concentration was higher when compost was applied. Despite the low rate of N output by crop uptake to N input by fertilization, systems including compost application did not result in excessive residual soil nitrate-N, on condition that the additional mineral fertilizer N was adapted to the economic optimum level. After four years of application, the use of VFG compost resulted in important storage of soil organic matter and nitrogen.

For these reasons, compost and slurry should not be judged along the same lines when the potential environmental (N) threats are considered.

Acknowledgements

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FATE OF C AND N POOLS – EXPERIENCE FROM SHORT AND LONG TERM COMPOST EXPERIMENTS

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Introduction

Compost has since long been used to improve soil fertility. Prior to the utilisation of mineral fertilisers, compost often was the only source of nutrients, and in biological and ecological farming this situation still exists. Apart from its function as a nutrient source, compost is applied to soils to maintain or increase the organic matter content of the soil (SOM), resulting in improved moisture and temperature characteristics, a lower bulk density and an increased biological activity. Compost is not only applied in agriculture, but also in horticulture, forestry and in situations where soils need to be reclaimed.

Compost is the product of mostly aerobically processed organic (waste) materials, with a broad origin. Compost may originate from sewage sludge, municipal solid waste (either or not collected in separate organic and inorganic fractions), bark, wood chips, agricultural waste products including manures or any mixture of these materials. During composting organic matter from the raw products is microbiologically degraded, resulting in a final product containing more or less stabilised carbon, nitrogen and other nutrients in the organic fraction, the stability depending on the compost maturity. The content of mineral nitrogen is generally relatively low, since N is partly lost during composting due to volatilisation.

The fate of nitrogen after the application of compost is important for growers who apply compost as a source of nutrients (especially in biological farming systems), but also with respect to the environment. Any excess of N may leach to groundwater and surface waters, or may affect the atmosphere. The fate of carbon is especially important with respect to other soil parameters like moisture retention, CEC and soil biological activity.

This paper describes the fate of carbon and nitrogen pools in soils applied with compost. Results from short-term and long-term experiments from the literature and from unpublished experiments are presented.

Compost and soil organic matter

There is a lot of evidence in the literature that application of compost leads to an increase in the soil organic matter (SOM) content (Delschen, 1999, Giusquiani et al, 1988, Leifeld et al, 1998, Pascual et al, 1999, Zan et al, 1987). There are several factors that determine the effect of compost on the SOM content. In many cases there is a positive relation between the amount of compost applied and the resulting SOM content (Delschen, 1999, Imagawa et al, 1989, Loebel et al, 1982). Other factors that affect the resulting SOM content are the type of material applied (Delschen, 1999) or the soil type (Leifeld et al 1998) and last but not least the maturity of the compost. The effect of maturity is best reflected in those experiments where the application of compost is compared with, for instance, that of (uncomposted) green manure (Table 1). Mature compost leads to higher SOM contents than uncomposted materials, even if comparable amounts of organic matter are applied. This is mainly caused by the fact that most of the labile organic components have already been decomposed during the composting process, leaving the more resistant organic components behind in the compost. These more resistant components are mineralised at a slower rate than ‘fresh’ organic materials and therefore they lead to higher SOM contents (see mineralisation of carbon and nitrogen). Lignin is one of the components in plant material that is more resistant to decomposition and in compost amended plots, 13C NMR spectroscopy demonstrated that lignin content was increased compared to control plots (Leifeld et al, 1998).

Table 1. Effect of different organic products applied from 1952 to 1980 on SOM formation at the van Bemmelenhoeve (De Haan and Lubbers, 1984)
FYM, farm yard manure (composted); GM, green manure; MOW-C (PS), municipal organic waste compost; SS-C, composted sewage sludge

	FYM	GM	Peat moss	MOW-C	SS-C
added organics kg/ha	98 100	116 000	164 025	103 380	67 920
humus produced	17 400	6 900	66 000	18 600	14 700
conversion %	18	6	40	18	22

Carbon

Compost is a complex mixture of organic and inorganic components. It contains dissolved organic carbon (DOC) and solid components in a range from labile to resistant with respect to degradability. DOC may be decomposed in soil, but DOC may also leach to the ground water (Kaplan et al, 1995).

When compost is added to soil, at least part of the solid organic carbon is decomposed further by organisms of the soil food web. Micro-organisms play a predominant role in this food web (Zwart et al 1994). Carbon dioxide, microbial biomass and more resistant organic matter are the main products of this decomposition. Application of compost may indeed lead to an increase in microbial biomass and enzyme activity (Garcia-Gill et al, 2000).

The rate of CO2 production is a good indicator of the decomposition rate. Laboratory incubations show that the decomposition rate of most composts is rather slow (Table 2A), depending on the maturity of the compost. Uncomposted materials showed a higher respiration rate than composted materials (Table 2, Thompson and Nogales, 1999), and during composting the mineralisation rate decreases (Bernal et al, 1998). Decomposition rates in soil are generally, but not always higher at higher temperatures and are affected by the soil type. In sandy soils they are generally higher than in clay soils (Bernhal et al, 1998) probably the result of protection of organic matter in clay (Hassink et al 1995). Leinweber and Reuter (1992) found increased proportions of C an N in the clay fraction compared with the sand fraction of soils, after long-term compost application. The fate of carbon is schematically presented in Fig. 1.

Table 2. Mineralisation of compost carbon.
Unless otherwise, all products have been composted

Product	C-mineralisation (%)1)	Period (days)	Conditions 2)	Reference
SS-cotton waste fresh	62.3	70	L	Bernhal et al, 1998
SS-cotton waste medium-mature	22.3			
SS-cotton waste3) mature	19.8			
MSW 4)	8	60	L	Sikora, L.J and Jakovcheno, 1996
Biolsolids	14			
SS 3)	16	54	L 22 °C	Tester et al, 1977
Manure fresh	35	175	L	Hartz et al, 2000
Manure	14			
Plant residue	14			
Farm yard manure	5,3	54	L 20 °C	Zwart, unpublished
Flowering bulb	1			
MOW 5)	5			
MOW-fresh	36	112	L 5 °C	Chodak et al, 2001
	54		L-25 °C	
MOW mature	1		L 5 °C	
	6		L-25 °C	

1). % of organic N; 2) F, field; L laboratory; G, greenhouse; 3) SS sewage sludge, 4) MSW, municipal solid waste; 5) MOW municipal organic waste

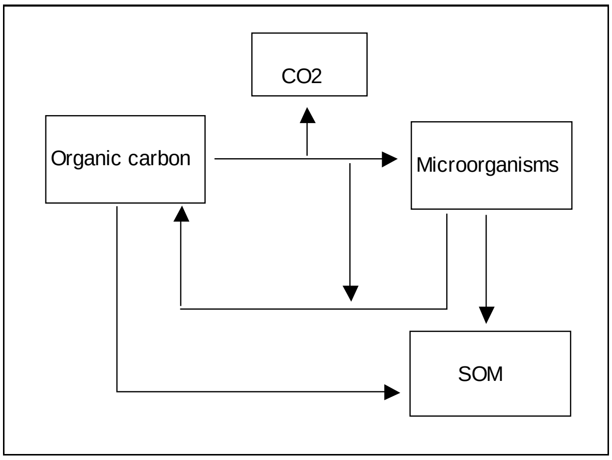

Fig. 1. The fate of compost carbon pools in soil (schematically)

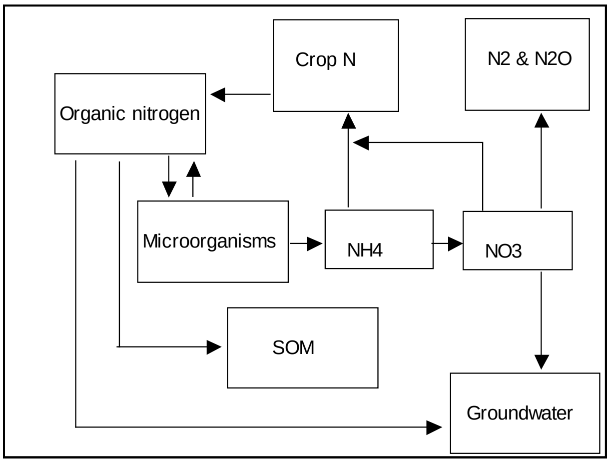

Fig. 2. The fate of compost nitrogen pools in soil (schematically)

So, its decomposition rate may be a good indication of the short-term effect that compost will have on the soil carbon content. However, field conditions differ from laboratory conditions and therefore, actual long-term effects of compost on soil conditions can only be demonstrated in long-term field experiments.

Nitrogen

Like carbon, nitrogen is also present in compost as a complex mixture of both inorganic and organic nature. The fate of compost nitrogen is schematically presented in Fig. 2. In organic dissolved form (DON) it may leach to the ground water just like DOC (Kaplan et al, 1995) Due to decomposition nitrogen is mineralised to ammonium, of which part is utilised by micro-organisms. In situations of unfavourable C:N-ratios of the compost, additional mineral nitrogen is taken up from the soil itself (immobilisation, Bernhal et al, 1998, Sims, 1990). As for carbon, the fraction of organic N that is mineralised differs between different composts, but in general it is low. (Table 3).

Table 3. Mineralisation of compost NITROGEN.
Unless otherwise, all products have been composted.

Product	N-mineralisation (%) 1)	Period (days)	Conditions 2)	Reference
Cattle manure fresh	21	150 (winter)	F	Eghball, 2000
Cattle manure	11			
Biosolids	23	365	F	He et al, 2000
Yard waste	23.5			
Municipal organic waste	48.4			
Biosolids	19-57		L	Nikolaidis et al 1999
Biowaste	5-7	500	L	Siebert et al1998
SS-cotton waste medium mature 3)	5.45	70	L	Bernhal et al, 1998
SS-cotton waste mature	9.12			
Pig slurry	0.5-3		L 30 °C	Benitez et al, 1998
Pig slurry	2.2-4.7		L 15 °C	
Several	< 3	140	G	N'Dayegamiye et al, 1997
SS 3)	6	54	L 22 °C	Tester et al, 1977
Manure fresh	15	175	L	Hartz et al, 2000
Manure	6			
Plant residue	2			
Cattle manure	11-29	224	L 30 °C	Hadas & Portnoi, 1994
MOW-fresh	1.8	112	L 5 °C	Chodak et al, 2001
	14		L-25 °C	
MOW mature	10		L 5 °C	
	10		L-25 °C	

1). % of organic N; 2) F, field; L laboratory; G, greenhouse; 3) SS sewage sludge, 4) MSW, municipal solid waste; 5) MOW municipal organic waste

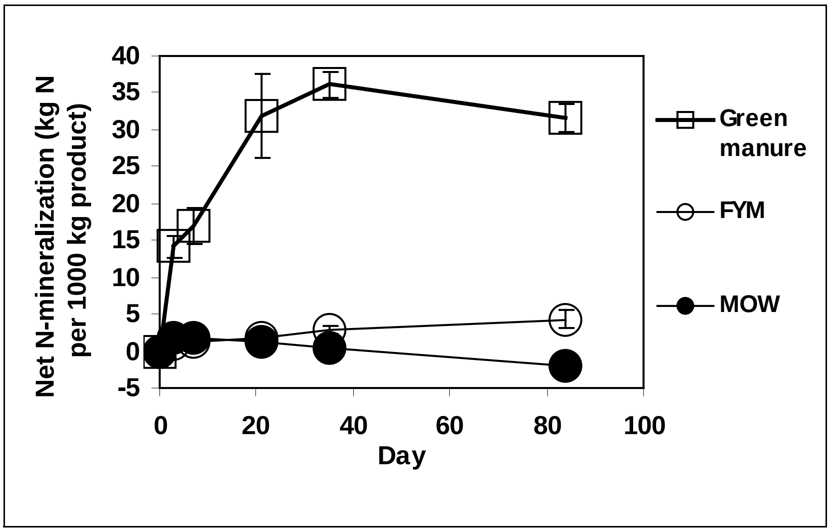

Fig. 3. Nitrogen mineralisation rate of compost compared with Farm yard manure and crop residues (MOW, Municipal organic waste, FYM, composted farm yard manure, Zwart, unpublished)

The mineralisation rate of compost is slow, compared to for example crop residues (Fig. 3, Zwart, unpublished). Ammonium produced during decomposition may be utilised by plants directly or it may first be nitrified to NO_3 (Heller, 1999) and taken up afterwards. Nitrate is also subject to leaching to the ground water and to denitrification to N_2 or N_2O. Compost application may result in an increased nitrate concentration in the ground water, especially if heavily applied (Kliebsch et al, 1998), but it may also reduce nitrate leaching (Diez et al 2000).

Long term effects

For a study of the eventual development of organic matter or organic nitrogen in soils, long term experiments are extremely valuable, since changes in both parameters are of a slow nature (Shen-Lin A, et al, 1996). Delschen and Vetterlein (1997) found accumulation rates between 0.02 and 0.08% SOM per year, depending on treatment and application rate, and the values decreased with time. On grasslands, Riem-Vis (1984) found an increase of 0.2% per 25 m3 compost given annually. The slow rate of accumulation is mainly caused by the high background values of total C and N most agricultural soils. For example a 25 cm layer of top soil with 1.5% organic matter and a bulk density of 1.25 kg per L, contains 47 tonnes of SOM. In addition, added organic material is partly degraded in soil, so in order to increase the SOM content structurally, large amounts have to be added, or, alternatively, smaller amounts have to be applied over a long period of time.

The numbers of long term experiments where compost has been applied over longer periods of time are relatively small. In the late 19th and early 20th century many long term agricultural experiments have started, of which only a few still exist. J.B. Lawes and J.H. Gilbert started the oldest still functioning experiment in 1843 at Rothamsted Experimental Station in England. Other well-known examples are Sanborn in the United States and Askov in Denmark (Steiner and Herdt, 1995, see also www.icsu-scope.org/downloadpubs/scope47/contents.html).

The results of many of these long term experiments show that the SOM and total N content of the soils remains the same or decreases when no organic fertiliser is applied. Crop residues are sometimes, but not always able to maintain the SOM at a constant level. In an experiment on a sandy soil at the former Institute of Soil Fertility, Haren, the Netherlands, that started in 1911 and ended a few years ago, one of the sub plots remained uncropped from the start until 1950 and it received no fertilisers at all. Another plot was cropped annually without organic fertiliser.

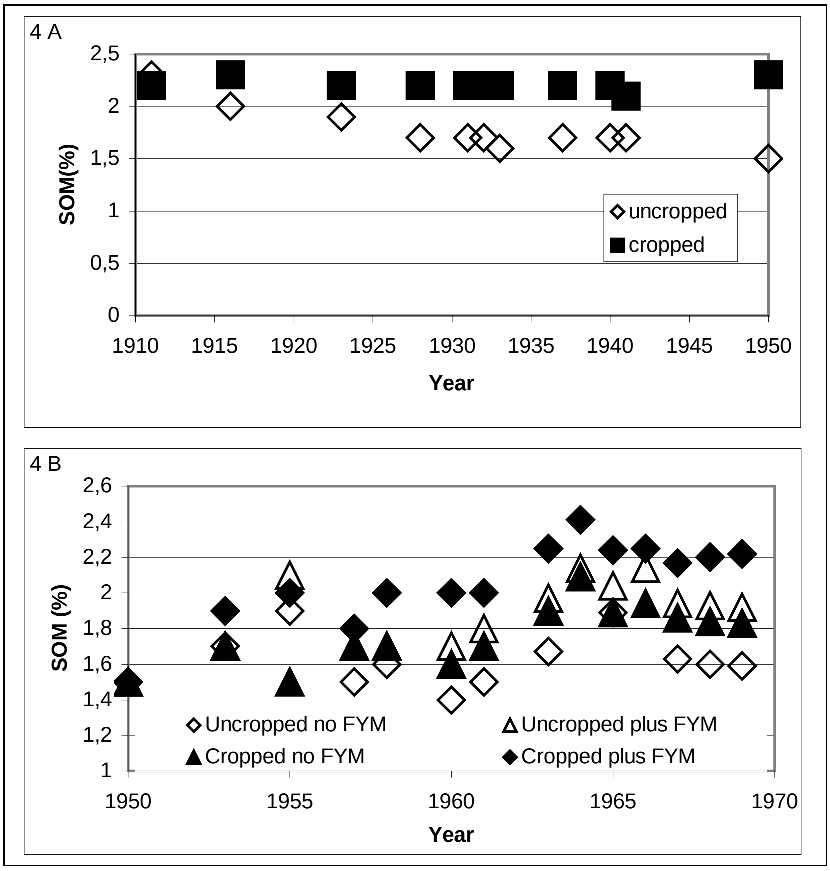

Fig. 4. Soil organic matter in an uncropped unfertilised soil and a cropped soil applied with chemical fertilisers A period 1911-1950, B, Period 1950-1969 after the uncropped plot was split in four. (FYM, composted Farm yard manure; Kortleven, 1963 and unpublished results)

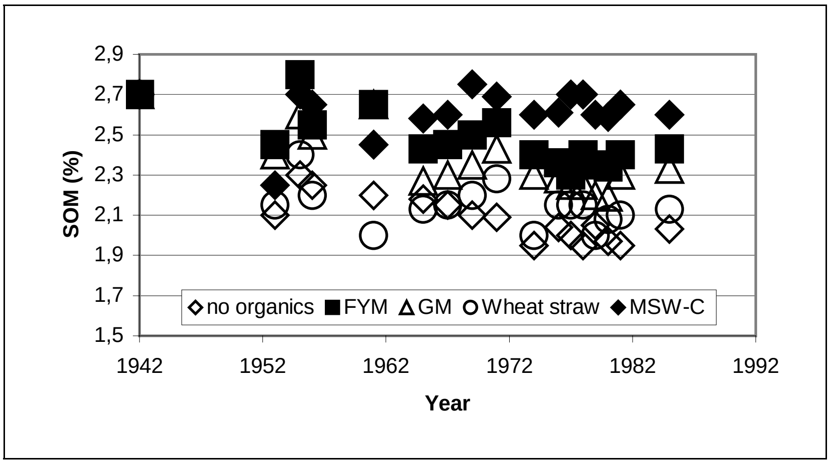

Fig. 5. The effect of long-term application of compost and other organic products on the soil organic matter of a Dutch loam soil at the Van Bemmelenhoeve. (FYM, composted farm yard manure, GM, green manure as crop residues, MSW-C, municipal solid waste compost, unpublished results)

The effects of these treatments on SOM are shown in Fig. 4A. In 1950 the uncropped plot was split into four subplots: unfertilised/uncropped, unfertilised/cropped, FYM/uncropped and FYM-cropped. The effects are shown in Fig. 4B. Kortleven (1963) was among the first who derived the annual degradation rate constant for SOM from the results of this and other experiments.

In Fig. 5 the effect of FYM is compared with that of green manure (GM) and municipal solid waste compost (MSW-C), in a field experiment that started in 1933 at the Van Bemmelenhoeve, the Netherlands and was ended with the end of this experimental farm in 1998 (unpublished results). The SOM content decreased slowly when no organic fertilisers were applied. Also after application of green manure, wheat straw, and FYM, SOM remained decreasing but at a slower pace.

Only after application of MSW-compost, SOM could be kept at a constant level. Similar results were obtained in another long-term field experiment in the Bommelerwaard (the Netherlands, De Haan and Lubbers, 1984, Fig 6).

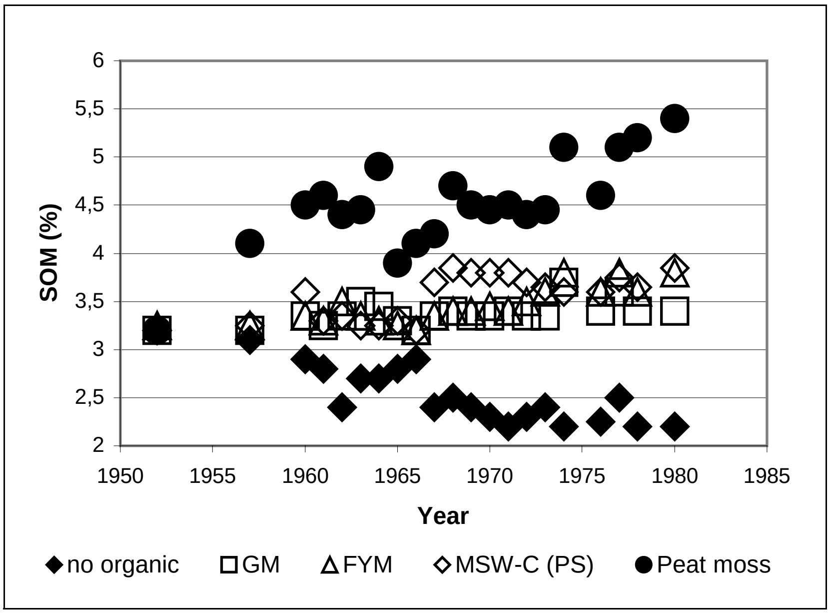

Fig. 6. The long term effect of no organic fertiliser and organic fertiliser on the SOM of a Dutch heavy fluviatile clay soil (FYM, composted farm yard manure, GM, green manure as crop residues, MSW-C (PS), municipal solid waste compost after preselection of the organic fraction, De Haan and Lubbers, 1984)

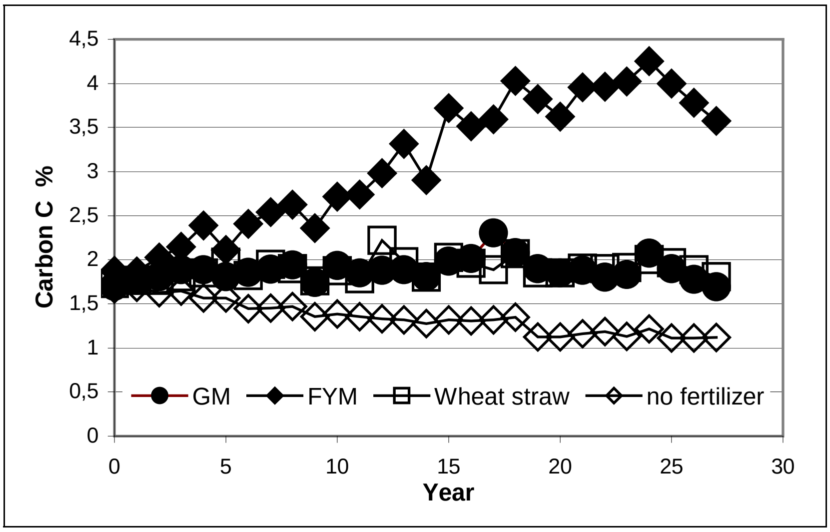

Fig. 7. The long term effect of no organic fertiliser and organic fertiliser on the SOM of an uncropped Dutch heavy clay soil (GM, green manure, FYM, composted farm yard manure, unpublished results)

Only here green manure kept SOM at the same level, a slight increase occurred after FYM or MSW compost, while peat moss application resulted in a markedly increase in SOM (see also Table 1).

In many of these long-term experiments SOM is not only affected by compost or another organic product, but also by organic crop residues. In Fig 7 the effects of compost application are shown, when no crop is grown at all. This plot experiment with loam and clay soils that started in 1961 at the Institute of Soil Fertility at Haren and it still exists at Alterra at present. In one part of this experiment similar amounts of C from different organic products were applied annually, while no crop was grown. The effect on SOM was followed and compared with a plot receiving no fertiliser at all. In the plots receiving no organic fertiliser, SOM carbon decreased gradually, whereas it remained approximately unchanged in the plots receiving straw or GM or wheat straw. Only in the plots fertilised with composted FYM, SOM increased. The amounts of carbon added annually were rather high, representing 63 tonnes of FYM.

Both short-term and long-term-experiments have been used to develop computer simulation programmes (Jenkinson et al, 1994). The degradation rate constants for organic matter are among the most important parameters for such models. In most of these programmes different organic pools are distinguished in separate compartments each with its own degradation rate (Jenkinson et al, 1994) while others consider simply one pool with a decreasing degradation rate in time (Jansen, 1984). A lot of information on these simulation programmes can be found on the internet: *www.iacr.bbsrc.ac.uk/res/depts/soils/somnet/tintro.html* & *www.dino.wiz.uni-kassel.de/model_db/models.html*

The results of computer simulations may help to assess the short-term and long-term effects of compost utilisation on soil and on the environment. They also can be used to investigate the effect sequestering carbon in the soil by compost application. Due to its low decomposition rate, compost seems to be a good candidate for this purpose.

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N_2O LOSSES FROM A LONG-TERM COMPOST AMENDED SOIL

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Introduction

Nitrous oxide (N_2O) is a trace gas of high ecological relevance because of its catalytic effect on ozone depletion in the stratosphere and its contribution to the global greenhouse effect. About 70 % of the annual global anthropogenic N_2O emission derives from agriculture (animal and crop production) (Mosier, 2001). One of the most important sources for N_2O is microbial transformation in soil (nitrification, denitrification). Essential factors affecting the formation of nitrous oxide in soil are the availability of oxygen (aeration, water logging), nitrogen (NH_4 and NO_3 from mineralization and fertilization), and carbon. Therefore usually higher N_2O emissions are measured on soils after long-term application of organic fertilizers (Kilian et al., 1998; Mogge et al., 1999; Kaiser and Ruser, 2000).

Due to differences in content and quality of organic matter (C/N ratio, degree of humification), compost application, compared with slurry, leads to a higher humus accumulation in soil.. In two field experiments described by Kilian et al. (1998) it was investigated, whether these differences in organic matter effect the N_2O emission.

Material and Methods

Table 1. Description of the field trials

Trial I: biowaste compost	
'- compost':	without compost
'+ compost':	4 years of compost application (in total 1200 kg N_t ha^{-1}), last application 180 kg N_t ha^{-1} October 1995
crop rotation:	winter wheat (1995) - oats (1996) – silage maize (1997)
mineral fertilizer 1996:	2 x 30 kg N ha^{-1} CAN for all plots
Trial II: cattle slurry	
'- slurry':	without slurry
'+ slurry':	6 years of slurry application (on average 120 kg N_t ha^{-1} a^{-1}), last application spring 1995
crop rotation:	winter barley (1995) – silage maize (1996) – winter wheat (1997)
mineral fertilizer 1996:	60 kg N ha^{-1} CAN for all plots

Both experimental sites were situated closely adjacent.. The soil was a brown earth from loess loam. The trials differed in the number of years with organic fertilization and in crop rotation

(Table 1). The crops cultivated in the period of investigation (April 1996 – March 1997) implicated differences in soil tillage (date, intensity) and date of supplementing mineral fertilization (total fertilizer amount uniformly 60 kg N ha^{-1} as calcium ammonia nitrate, CAN).

N_2O fluxes were measured three times per week at 8 sites within each plot using the 'closed chamber' technique described by Hutchinson and Mosier (1981). CO_2 fluxes were determined as a 'by-product', validated from Freijer and Bouten (1991). Every third week denitrification potential (denitrifier enzyme activity) was determined in fresh soil samples with a modified method described by Tiedje (1994). In this anaerobic short-term incubation the current population of denitrifying micro-organisms is the only limiting factor for the observed denitrification rates. Total microbial activity in the soil sample is reflected, because the majority of soil micro-organisms is capable for denitrification.

Results and discussion

The soils differed in the initial content of organic matter (Table 2, without organic fertilizer in total approx. 0,5 % lower C_{org} content in trial I). Compost application (trial I) increased C and N contents significantly stronger (39 and 46 % resp.) than slurry application (trial II; 4 and 6 % resp.). This is mainly due to higher amounts of organic matter applied by compost fertilization (slurry: approx. 6 t C ha^{-1}, compost: approx. 14 t C ha^{-1}). Compared to the large amount of C, the differences in quality of organic matter (degradation rate) are thought to be less relevant..

The time pattern of gas fluxes (presented by Kilian et al., 1998) in each trial was influenced by soil tillage and mineral nitrogen application as related to cultivated crops. Therefore only total amounts of N_2O and CO_2 emissions, measured between April 1996 and March 1997, and the mean denitrification potential during the year 1996 were considered in the following (Table 2).

Table 2. Effect of long-term organic fertilization on soil organic matter, microbial activity, C_2O and N_2O emission

	C_{org}	N_t	Denitrification potential average of 1996	CO_2-C	N_2O-N
	——— %	———	mg N (kg soil DM)$^{-1}$ d^{-1}	t ha^{-1} a^{-1}	kg ha^{-1} a^{-1}
Trial I					
- compost	1,26	0,182	6	10	7,0
+ compost	1,84	0,253	13	15	8,3
Trial II					
- slurry	1,79	0,235	12	10	4,1
+ slurry	1,90	0,245	16	11	5,7

The denitrification potential was closely related to the organic matter content of soil. This is in agreement with the frequently described correlation between microbial activity and C_{org} content (Beck, 1984; Anderson and Domsch, 1989; Beck et al. 1995).

In contrast to this, the CO_2 emissions from all plots were not related to C_{org} content of soil (table 2). However in each single trial the increase in CO_2 emission following organic fertilization (trial I: approx. 50 %, trial II approx. 10 %) corresponded well to the increase of C_{org} (39 and 6 % resp.). This shows that higher C availability in soils enriched with organic matter effected microbial activity in field in the same way as it was reflected by denitrification potential. The relatively low CO_2 emission in trial II, when compared with trial I, may be due to a less intensive soil tillage (e.g. no tillage in summer after harvest) and its influence on aeration and microbial access to organic matter (destruction of aggregates). In addition the measured CO_2 will not only originate from degradation of organic matter, but may also derive from root respiration and microbial degradation of root C compounds. Thus the total amount of CO_2 emission was directly and indirectly influenced by the different crops cultivated. Within each trial plants developed uniformly. Therefore an influence of crops on relative differences between corresponding treatments (with or without organic fertilizer) may be disregarded.

This is also true for N_2O emission. Nevertheless, in contrast to CO_2 emission and denitrification potential N_2O emission was related neither to C_{org} and N_t content of soil nor to its increase following organic fertilizer application (increase in N_2O emission: trial I 19 %, trial II 39 %).

N_2O is formed by nitrification and denitrification. A higher nitrogen mineralization from organic matter increases nitrification, a higher nitrate supply promotes denitrification. Compared with control plots soils treated with organic fertilizers had higher nitrate contents during the year (Kilian et al., 1998). In tendency this increase was higher in trial I with a stronger accumulation of soil nitrogen by long-term compost application. Thus the comparably low increase in N_2O loss in this trial could not be explained. A more balanced, slower nitrogen mineralization on compost treated soils which is assumed to correspond more closely to plant uptake could not explain the differences in relative N_2O emission between the two trials either. A very high C availability and therefore marked oxygen depletion in soil not only promotes denitrification, but will also lead to a further reduction of N_2O to N_2. The portion of N_2O on total amount of denitrified N is reduced (Granli and B∅ckman, 1994). Thus N_2O emission may be comparably low, despite of high denitrification rates. This might be the main reason for the relative low N_2O emission from compost treated soil. From the amount of CO_2 emission (see above) it can be concluded that the higher C availability following compost application is due mainly to the stronger accumulation of organic matter. There is no evidence that differences in quality of organic matter from compost and slurry will effect N_2O emission in the long term.

The effect of higher soil aeration as a consequence of a larger proportion of macro-pores in long-term compost amended soil (Ebertseder and Gutser, 2002) is difficult to be evaluated. Nevertheless this might have substantially contributed to reduce denitrification rate.

On the whole, general conclusions hardly can be deduced from these trials and if at all, only with strong restrictions. But the results point out that, despite a strong accumulation of humus by compost application, ecological relevant N_2O emissions might be low when compared to other organic fertilizer treatments. This first indication should be followed up by further investigations.

Summary

In adjacent field trials long-term application of biowaste compost and slurry increased humus content of soil, followed by higher microbial activity and CO_2 emissions. Compared to slurry, the higher accumulation of humus by compost resulted only in a low increase of N_2O emission. The reason for this could not clearly be deduced from these trials. Nevertheless the results point out that negative ecological effects of long-term compost application might be lower than would be expected from the strong accumulation of organic matter in soil.

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CO_2 EVOLUTION IN SOIL AMENDED WITH COMPOST

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Introduction

Soil carbon (SC) is constituted of an inorganic (SIC) and organic (SOC) fractions. Soil scientists indicate SOC formed by humified and not humified fractions (e.g. protein, carbohydrates, lipids) (Senesi and Loffredo, 1999). The inorganic C is constituted by carbonate (CO_3^{-}) and bicarbonate (HCO_3^{-}). SOC is more present in wet soils, as well as, SIC is typical for arid e semiarid soils (Izaurralde et al., 2001).

The importance of soil organic carbon is assumed due to its positive effect on the soil (Senesi and Loffredo, 1999), and is therefore becoming the main parameter for soil quality definition. The content of the organic matter in soil depends on output and input balance (Fig. 1). The capability of soil to store organic matter (OM) vary from 1 % for sandy soils to 10% for heavy soils (Izaurralde et al., 2001).

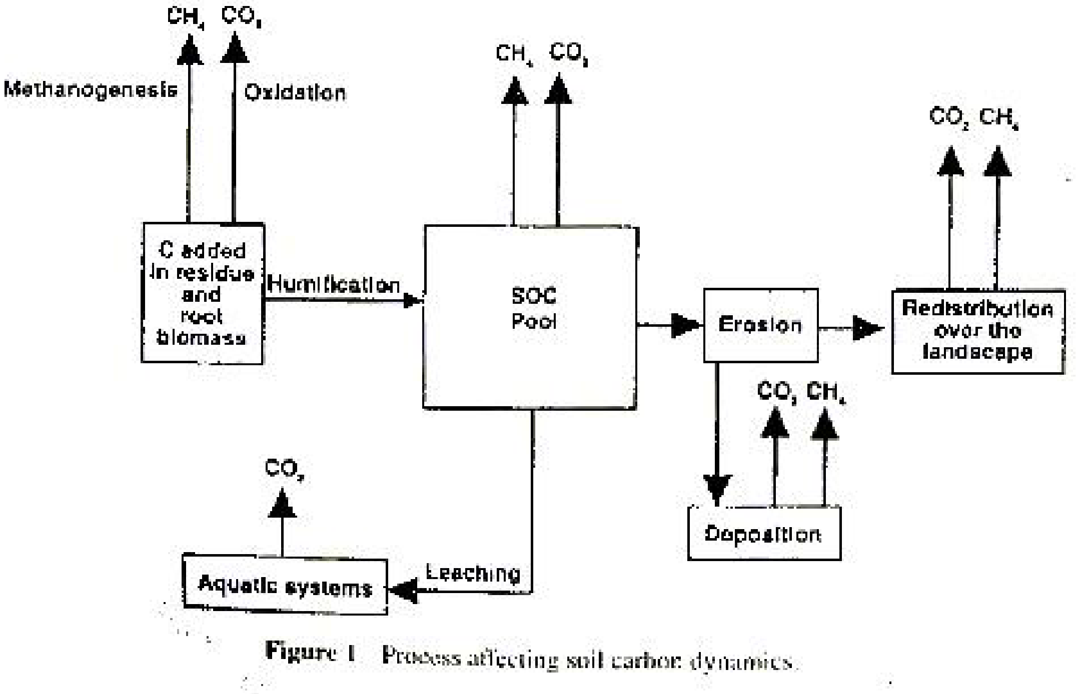


Fig. 1. Dynamic of carbon in soil (Lal, 2001).

In the Intergovernmental Panel on Climate Change (IPCC) Assessment, agriculture was estimated to be responsible for 20 % of the annual increase in anthropogenic greenhouse gas emission (Cole et al., 1996). In the last 300 years deforestation caused rapid increase of lands dedicated to agriculture, and it is the responsible for great CO_2 emission (Haas *et al.*, 1957; Mann, 1986). The agricultural intensive practices can lead to a sizable C depletion that can be minimized with maintenance agricultural techniques or by adding OM to the soil. This bring the soil becoming the main environmental compartments as potential CO_2 sink if part of the lost carbon can be regained (Paustian et al., 1997).

Material and methods

Experimental designed consisted in a field trial performed in North Italy. Three thesis made in duplicate (4x3 m each) were considered: control + compost dose A (0 Mg Ha^{-1}), control + compost dose B (50 Mg Ha^{-1}), and control + compost dose C (85 Mg Ha^{-1}). Compost used was obtained by mixing green waste and food scraps from municipal solid waste 1/2 (p/p). Soils were sampled at the beginning and at the end of experimentation. Total organic carbon, nitrogen, pH, ash, CEC, P, K, Mg, Ca and heavy metals were detected by typical analytical analysis (data not show).

Table 1. CO_2 emitted from thesis A, B and C

	A		B		C	
Date	CO_2 ± SD (g/h m^2)	CV %	CO_2 ± SD (g/h m^2)	CV %	CO_2 ± SD (g/h m^2)	CV %
30/05/00	0.39 ± 0.00 aA	0.0	0.92 ± 0.01 bA	1.1	1.08 ± 0.39 bB	36.4
23/06/00	0.62 ± 0.22 aB	35.5	0.85 ± 0.13 bA	8.7	1.00 ± 0.11 bB	11.3
14/07/00	0.60 ± 0.09 aB	15.6	0.87 ± 0.12 bA	13.6	0.93 ± 0.19 bA	20.2
28/07/00	0.82 ± 0.12 aC	14.6	0.99 ± 0.11 bA	11.4	1.19 ± 0.01 cC	1.2
21/08/00	0.76 ± 0.10 aC	13.0	0.90 ± 0.07 bA	7.9	1.03 ± 0.18 bC	17.3
01/09/00	1.23 ± 0.41 aD	33.5	1.19 ± 0.04 aB	3.0	2.20 ± 0.24 bD	11.1

Number followed by the same letter are not statistical different
SD…standard deviation; CV %…coefficient of variation

Carbon dioxide emissions were recorded by using a new scientific apparatus (COMBICO_2) (DiProVe, Milano Italy; Costech International, Cernusco S.N., Italy). Experimental thesis were amended with compost and typical tillage were adopted before plant seeding. Plant used was maize cv Lolita Single Cross, FAO class 600.

Main results

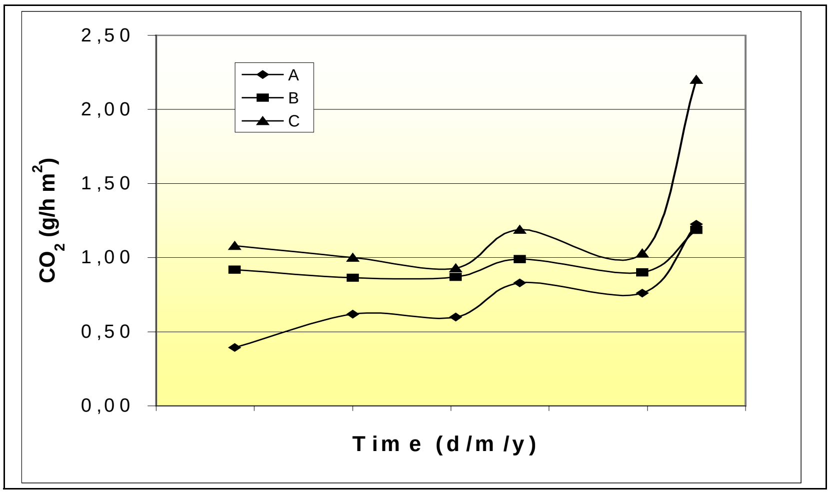


Fig. 2. CO_2 emission for the three thesis studied

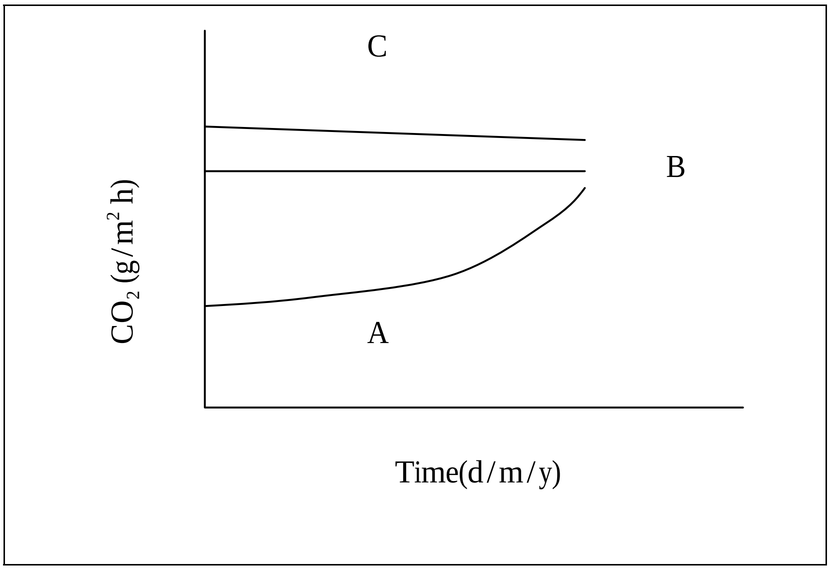


Fig. 3. CO_2 emitted from thesis A, B, and C

Table 1 shows the results of the emission of carbon dioxide from the three thesis during experimentation. As expected, emission was greater for thesis with highest compost dose (C)(Fig. 2). Data of September first, showed an anomalous trend (Fig. 2). This was due probably to the rapid increase of soil respiration at the end of the crop cycle, because of the degradation of plant residues.

If these data are not considered we obtain what is reported in Fig. 3. In particular, thesis A showed an exponential increase, contrarily to the thesis B and C that showed similar CO_2 production for all period. From the observations of the thesis A, we noted that the respiration was due to plant growth, indicating roots respiration as the main responsible for carbon dioxide production.

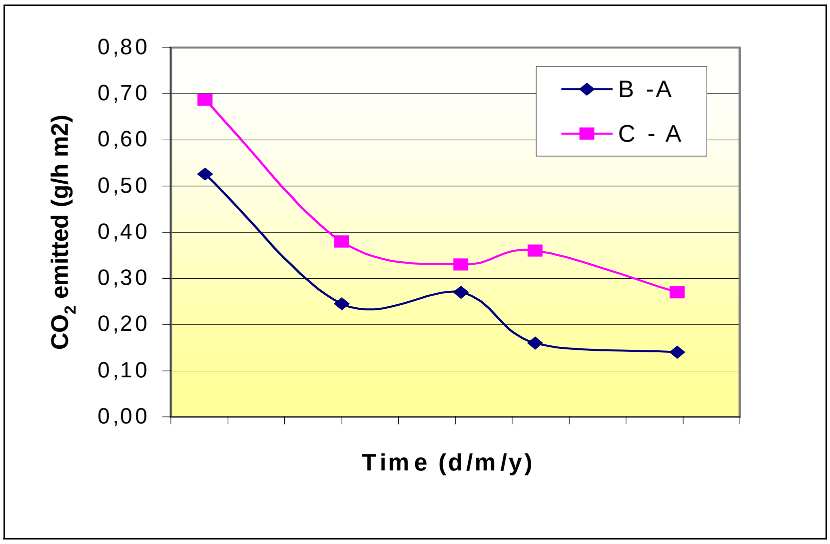


Fig. 4. CO_2 emitted from thesis B, and C, by subtracting background values (thesis A) from total respiration.

We can assume respiration for thesis A as a background value (Silvola, 1996). For the thesis B and C, we have to add compost respiration to the background values.

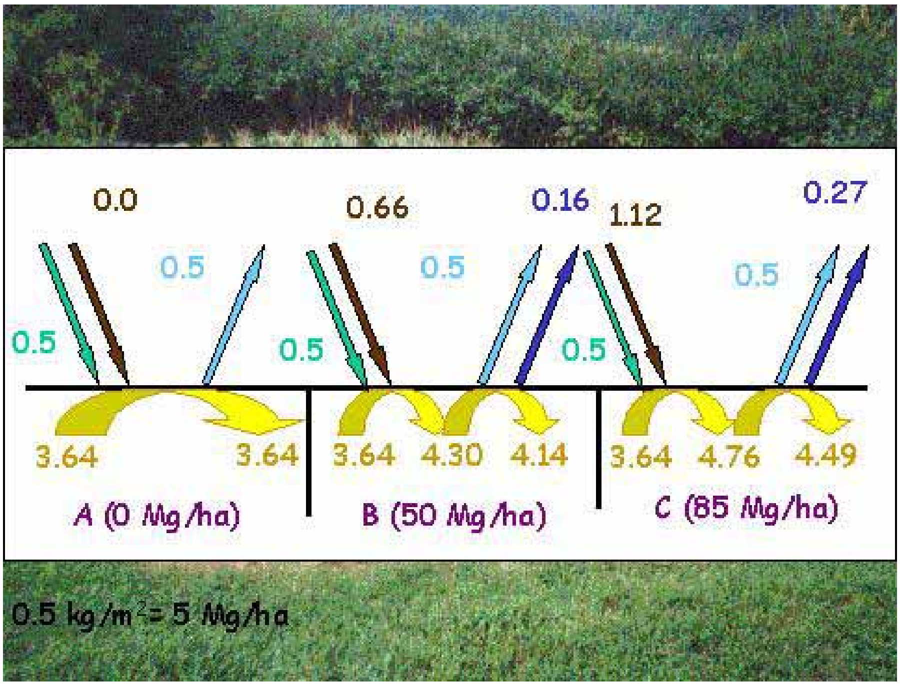
By subtraction of the background value (thesis A) from the total respiration occurred for thesis B and C, we calculated respiration rate due to the compost added (Fig. 4).

From CO_2 data, it is now possible to calculate the degradation kinetics for compost (Jenkinson e Rayner, 1977) (Table 2). It was very interesting to note that, independently by the compost dose, reaction rate (k) and $t_{0.5}$ were exactly the same for the two compost doses utilized. That was what we expected, being compost used the same type for both thesis. Obviously, respiration is higher at the start of the trial being the kinetics of the first order (see later).

Table 2. k and $t_{0.5}$ values calculated for compost

$year^{-1}$	Thesis B: k_{Ct}	Thesis C: k_{Bt}
	0.70	0.75
year	Thesis B: $t_{0.5\ Ct}$	Thesis C: $t_{0.5\ Bt}$
	0.99	0.93

Now, taking in consideration results of CO_2 emission, analytical data (soil C content), and what before discussed, we are able to propose a scheme that resumed total C balance in the three thesis studied (Scheme 1).



Scheme 1. Carbon mass balance: green arrows indicate input due to roots; brown arrows indicate compost C added; light blue arrows indicate output due to background respiration; blue arrows indicate compost respiration; yellow arrows indicate soil C content before and after experimentation

Input, due to root apparatus that remain in the soil, was counterbalanced exactly by soil background respiration; therefore for the control, no variation of C contents occurred. On the other hand, for thesis B and C, compost determined a greater input of C respect output determining C accumulation. The rate of C increase depended by the degradation rate and the dose of compost applied.

Conclusion

Results obtained suggested that the use of 50 and 85 Mg Ha^{-1} of compost determined an increase of the organic matter contents of 137 g kg^{-1} and 237 g kg^{-1}, respectively. Degradation coefficient determined for compost used indicated that soil was able to sequestrate about 760 g kg^{-1} of carbon added, becoming, compost, an important carbon sink for soil.

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FEASIBILITY AND NECESSITY OF PREDICTING COMPOST IMPACT ON SOIL ORGANIC MATER EVOLUTION ONCE IT HAS BEEN APPLIED

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INTRODUCTION

In order that the use of compost in agriculture could be considered as a sustainable benefit, it is necessary that its use would be in accordance with its characteristics and its quality. This can be illustrated considering the impact of compost application on soil organic mater evolution. If composts are not used in accordance with their characteristics and quality, there is a non-negligible risk that:

(i) composts used to enhance soil organic mater content would in fact mostly contain easily degradable organic mater, leading to high losses of NO3 in leachates, or

(ii) composts used to release nutrients for plants would mostly contain “stable” organic mater, leading to nutrient deficiencies for the growing crops.

Linères & Djakovitch (1993) to characterise organic matter in organic fertilisers through biochemical successive extractions developed the I.S.B. (Indice de Stabilité Biochimique, Index of Biochemical Stability) method and correlated the fractionation to a potential evolution of organic matter evolution once the organic fertiliser has been applied to the soil.

Robin (1997) adopted a similar approach with a simplified procedure. Based on the results of organic matter fractionation, he proposed also a classification of organic fertiliser in relation with a specific and appropriate use of the organic fertiliser.

Material and methods

Biochemical characterisation

CBM (Caractérisation Biochimique de la Matière organique, Biochemical Characterisation of organic Matter) characterisations were performed on more than 500 organic fertilisers, following the method published by Robin (1997). Fractions SOL, HEM, CEV, LIC[1] and mineral content were expressed as % of dry matter.

Products analysed were classified into 4 groups as proposed by Robin (1997). Considering in each of the four groups the average profile of fractionated organic mater and the amount of mineral material on one hand, and considering the agronomic information available on the products on the other hand, it appeared that they corresponded to:

(1) fertilisers for soil OM enhancement

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[1] SOL is the 1st extracted OM fraction, HEM the 2nd, CEV the 3rd and LIC the non extracted OM

(2) fertilisers for plant nutrition
(3) fertilisers having great amounts of mineral material
(4) fertilisers similar to vegetal residues (mostly untreated raw materials for composting).

A graphic representation of this classification in presented in Fig. 1.

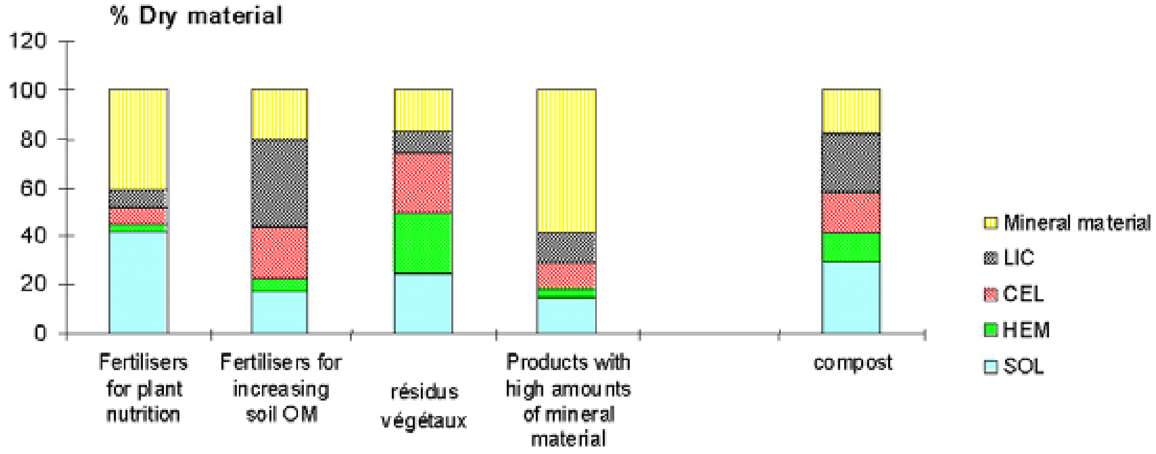

Fig. 1. Mean CBM profiles for the 4 classes proposed (Robin, 1997) and example of a compost CBM profile.

Estimation of non mineralisation organic mater

Studies of compost C mineralisation after application on soil were performed under laboratory conditions on 8 products, chosen among the database for the variety of their organic mater fractionation. A regression enabled to established a method of calculation using OM fractions and mineral fraction of the product to predict the proportion of non-mineralised organic mater (Tr) (Robin, 1997).

Statistical exploitation of Database

Results concerning composts were extracted from the whole database into a compost-sub-database. Average and standard deviations were calculated for SOL, HEM, CEL, LIC fractions and mineral content and Tr for the whole database and the compost-sub-database. Same information were also obtained from a sample extracted from the compost-sub-database and concerning specifically green wastes composts.

The initial classification of products was proposed after the realisation of a Principal Component Analysis realised on the 60 first products analysed (Robin, 1997). The appropriate affection of new references was checked through a Discriminant Factorial Analysis.

Results and discussion

The compost-sub-database contains more than 280 references of various composts. The database reduced to green wastes compost accounts for more 130 references.

Statistical calculation performed on the whole database, the compost-sub-database and the database reduced to green wastes compost are reported in Table 1. Considering the standard deviation, for each fraction, the mean value calculated for the compost-sub-database is neither significantly different from that of the whole database nor from that of the database reduced to green waste composts. In addition, coefficients of variation are similar in the 3 databases even if a slight decrease can be observed from the whole database to the compost-sub-database and from the compost-sub-database to the database reduced to green waste composts.

The variability of organic matter fractions observed among more than 280 composts, is then similar to that observed among more than 500 organic fertilisers of any kind. Moreover, the same remark can be made for the variability of Tr, estimating the potentially non-mineralisable organic matter of the organic fertiliser.

Further, the variability of organic matter fractions that is observed among more than 130 green waste composts, is then similar to that observed among more than 280 composts of any kind and the same remark can be made for the variability of Tr.

Table 1. Average and standard deviation (italic) or organic fractions SOL, HEM, CEL and LIC and Tr as determined by the CBM method and expressed in % of dry material.

	SOL	HEM	CEL	LIC	Min Mat	Tr
	(% dry material)					
Whole database	19 *10*	6,8 *6.4*	17 *11*	17 *11*	40 *19*	30 *22*
Compost-sub-database	15 *6*	5 *4*	15 *9*	18 *8*	47 *17*	27 *18*
Green Wastes composts	14 *5*	5 *3*	15 *6*	19 *7*	47 *13*	27 *15*

The Factorial Discriminant Analysis showed that 89.6% of products were correctly affected to the class having the nearest centre of gravity. This confirms that the classification proposed by Robin (1997) for 60 references is still robust when considering more than 500 references.

The result of products' classification into the four classes is presented in table 2 for the compost-sub-database, in comparison to the whole database. For both databases, class 1 and class 2 contain each less than 10 % of products referenced in the corresponding database and class 3 and class 4 contain each more than 40 % of products referenced in the corresponding database.

Only slight differences can be observed between the whole database and the compost-sub-database concerning the repartition of products among the 4 classes.

Table 2. Repartition of products of databases among 4 classes of fertilisers

	Class 1	Class 2	Class 3	Class 4
Whole database	7%	9%	42%	39%
Compost-sub-database	1%	3%	46%	50%

1: Fertiliser for plant nutrition, 2: Fertiliser similar to vegetable residues, 3: Fertiliser for increasing soil organic matter level, 4: Fertiliser with high amount of mineral material.

It seems then that there is a huge variability among composts. Therefore, defining an organic fertiliser as “a compost” is not a discriminant information to determine the type of organic matter contained in the product (Table 1) and is not a discriminant information to permit the classification of the product among types of agricultural uses.

Most probably, raw material used to produce the compost influence the characteristics of the final product. However, raw material may also have variable qualities. In addition, composting processes are very divers, so that there is still a great variability in products even when considering similar raw material (Table 2). Fig. 2 illustrates this remark by showing the variability of CBM profiles for a selection of Green Wastes composts.

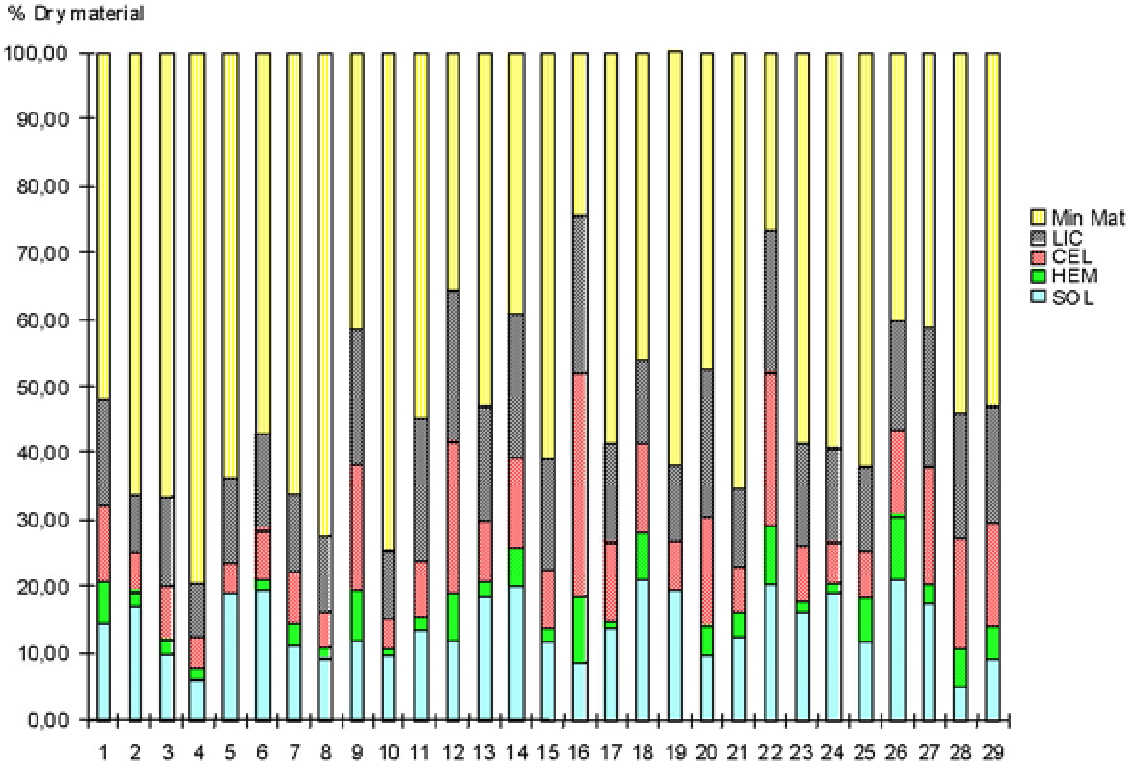

Fig. 2. CBM profiles for green-wastes extracted from the compost-sub-database.

Conclusion

Considering these results, it is not possible to predict possible evolution of organic mater after compost application on the soil, neither for compost in general, nor for types of composts regarding only the raw materials used. Therefore, it is necessary to characterise appropriately compost before using them in agriculture, so that the use will be in accordance with the specific properties and quality of the compost. This is fundamental not only considering organic matter evolution but also any other possible impact on soil and on the environment.

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ESTIMATING THE AMOUNT OF EXOGENOUS ORGANIC MATTER NEEDED TO RESTORE AND MAINTAIN FRENCH LOAMY SOILS AT A GIVEN ORGANIC LEVEL

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Introduction

Crusting and erosion in France

Erosion in plain is mainly due to the poor structural stability of the soil. Indeed if the soil structure is not stable, a strong rain (with intensity peaks above 30 or 40 mm/h, Robert, 1996) breaks the aggregates of the soil down. The particles or microaggregates separated from the aggregates clog in the interstices of the structure and so seal the surface. The water can not percolate any more and runoff starts.

The structure of soil depends on two main controlling factors : a loamy texture (the soil will be subjected to erosion risk if it contains less than 15% of clay, Robert, 1996) and a low organic matter contents (below 2 or 3%, Le Bissonnais and Arrouays, 1997).

In France the organic matter contents of cultivated soils decreased during the past decades (Balesdent, 1996). This is due to changes in land uses (Balesdent and Arrouays, 1999) with the specialisation of the agriculture, the suppression of the livestock farming and the substitution of grasslands by crops.

Two solutions can be proposed to solve this problem : reducing the losses of organic matter due to mineralisation by reduced tillage (Kern and Johnson, 1993) or increasing the input of organic matter by providing stabilised exogenous organic matter.

Indeed 3 types of organic matter with different actions on soil structure must be distinguished:

- the fresh organic matter which has an intense but very short action,
- the stabilised organic matter which has a long term effect,
- the very stable organic matter.

Fresh organic matters are easy to degrade and thus stimulate the microbiological activity. The secretions of the micro-organisms reduce the wettability of the pores surfaces and so increase the resistance to disaggregation by water. However fresh organic matters are quickly degraded.

The stabilised organic matters have a longer effect for two reasons :

1. they are longer to degrade, they regularly provide decomposition products, that stimulate the microbiological activity,
2. they favour the aggregation of the soil particles (Linères, 1993).

Among the different exogenous organic amendments, manure and composts are the largest available sources.

Composts : a source of organic matter

France produces approximately 1 million tonnes of urban composts annually, representing 7% of the municipal solid waste treatment in France. However, the organic fraction of solid municipal waste is estimated at 14 millions tonnes (ADEME, 2000) which could represent about 4.5 millions tonnes of composts. There is hence considerable potential to develop this treatment method, which is also being induced by a number of legal measures.

1. Organic fractions should not be landfilled from 2002 (the 1st of July) (13 of July 1992 decree),
2. The regulation of 1996 fixed an objective of 50% recovery (Voynet decree).

But this development would require a lot of efforts, so it is important to know if the compost really presents an interest for French soils.

Used as an organic amendment, the compost provides an important source of stable exogenous organic matter (second after manure). It can be produced anywhere in France, contrary to manure, generally produced in large quantities but in areas of specialised farming (dairy and meat production). The compost is used in wine growing, orchards and especially in arable land (cereals, beets, oleaginous plants, etc…) where the lack of organic matter induce crusting and erosion. Indeed, the surfaces subject to erosion in France are about 5 millions hectares mainly located in the Nord-Pas-De-Calais, Picardie and the Seine-Maritime as well as in the Rhone-Alpes and Midi-Pyrénées regions (Le Bissonnais et al, 1998).

The question addressed is : “how much exogenous organic matter do the French soils need to reach a given organic matter level that might protect them against excessive crusting, and is the local manure production enough to respond to this demand?”.

Materials and methods

Carbon threshold value

The carbon threshold for loamy soil beyond which structural stability may increase is subject to discussion. However most studies give a range of 1% to 1.5 % of carbon (Greenland et al. 1975 ; Grieve, 1980 ; Newbould, 1980 ; De Ploey and Poesen, 1985 ; Albrecht et al, 1992 ; Le Bissonnais and Arrouays, 1997). That is the reason why we did the calculation for 6 different carbon values : 1 – 1.1 – 1.2 – 1.3 – 1.4 – 1.5%

Estimation of the concerned area

We focused on the arable loamy soils with low organic matter content and exhibiting a significant erosion risk. Estimate and mapping of these areas were made by overlaying maps of parameters from several databases.

- the CORINE Land Cover map (Collectif, 1993),
- the French soils erosion risk map (Le Bissonnais et al, 1998),
- the French soils geographical database (1 : 1 000 000) (Jamagne et al, 1995; King et al, 1999),

- the French soils carbon database (17 000 points, Arrouays et al, in press).

Then for each soil type we calculated the average of the carbon content and the percentage of the values inferior to the carbon threshold. We used this percentage as an assessment of the percentage of surface concerned.

Estimate of the quantities of exogenous organic matter necessary

Hénin Dupuis formula

We used the Hénin-Dupuis model (Hénin and Dupuis, 1945) in its exponential form (Van Dijk, 1980). This model calculates the organic matter content as following :

$$y_t = \frac{K_1 x}{K_2}\left(1 - e^{-K_2 t}\right) + y_0 e^{-K_2 t} \tag{1}$$

Where :

- y_t is the quantity of stable organic matter at time t,
- x is the input of organic matter,
- K_1 is the humification coefficient,
- K_2 is the mineralisation coefficient.

K1 represents the ratio of the quantity of organic matter that increases the soil organic matter rate (equal to the stable organic matter) on the total organic matter quantity. K2 represents the annual rate of destruction of the organic matter. For our calculation we used the values given by Rémy and Marin-Laflèche (Rémy and Marin-Laflèche, 1976).

We calculated for each year the final organic matter yt with an input of organic matter x equal to :

1. the part of the crops residues returned to soil calculated below and,
2. a spread of 1.25 t/ha/y of stable organic matter (equivalent to a spread of 40 t/ha of manure every 2 years or a spread of 30 t/ha of compost every 3 years).

If the calculated yt is inferior to the carbon threshold, the quantity of stabilised organic matter necessary is considered equal to 1.25 t/ha/y and if it is superior, the quantity of stabilised organic matter necessary is equal to the minimum needed to maintain the threshold.

We did the calculation with a ratio organic matter/carbon equal to 1.724, a bulk density equal to 1.4, and for a depth of soil of 30 cm.

For manure, we used a K1 of 0.34 (Boiffin et al, 1986) and a value of 18% of fresh organic matter ; for composts, we used a K1 of 0.5, close to the values of biowaste or green waste composts (Le Bohec et al, 1999 ; Houot et al, 2000) and a value of 25% of fresh organic matter (ADEME, 1998). In both cases, we intentionally used coefficients that minimise the quantities of organic matter necessary.

Crop residues returned to soils

The fractions from the crop residues returning to soils are the roots (compulsory part) and the aerial parts that could be let in the field and buried or exported (optional part).

We calculated the quantities of stable organic matter brought to soil by the crop residues from the total areas of each crop in each department (Agreste, 1999) and the yield of stable organic matter (CERES software, Jones and Kiniry, 1986).

To avoid to count twice the cereals straw, we calculated the straws returned to soil from :

- the departmental cereal area (Agreste, 1999),
- the quantities of straw gathered in (from SCEES / BCPF),
- an average straw yield of 0.7 tonnes / hectare (Messmer, 1996; Agreste, 1999).

With these hypothesis the crop residues returned to soil represent nearly 16 millions of tonnes of stable organic matter.

Sources of exogenous organic matter

The main source of exogenous stable organic matter is manure which is generally produced locally and most often on the farm itself.

It was estimated that this source accounts for more than 86 millions of tonnes (fresh matter). We calculate the national manure production by French department from :

- the cattle estimation (Agreste, 1999) but we applied a coefficient 0.5 fort the bovine to take into account the time spent in grazing,
- the percentage of manure and slurry produced by each species (Pflimlin, 1999),
- the dejection production for each animal (CORPEN, 1988).

The local production is then compared to the quantities of stabilised organic matter necessary calculated, to determine the areas concerned by a lack of organic matter and the quantities of exogenous stabilised organic matter necessary.

Results

Concerned areas

The surface concerned by this study is 3.4 million hectares (Mha), accounting for 6% of the national surface and 17% of arable land.

This area declines to 2.7 Mha and 1.3 Mha respectively if we only consider the surface for which the carbon content is less than 1.5% and 1% respectively.

Amounts of organic matter necessary to restore and maintain threshold values

The quantities of stable organic matter necessary for restoration and upkeep expressed in amounts of composts are illustrated in Fig. 1.

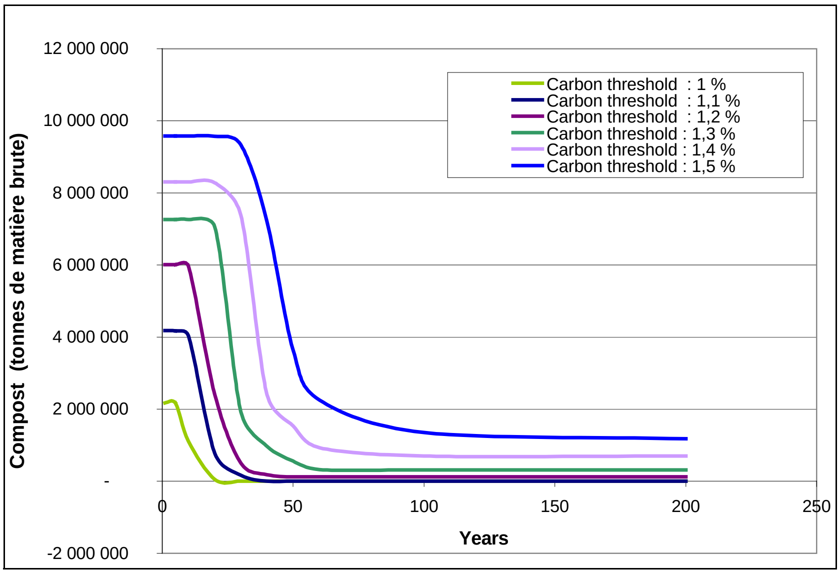


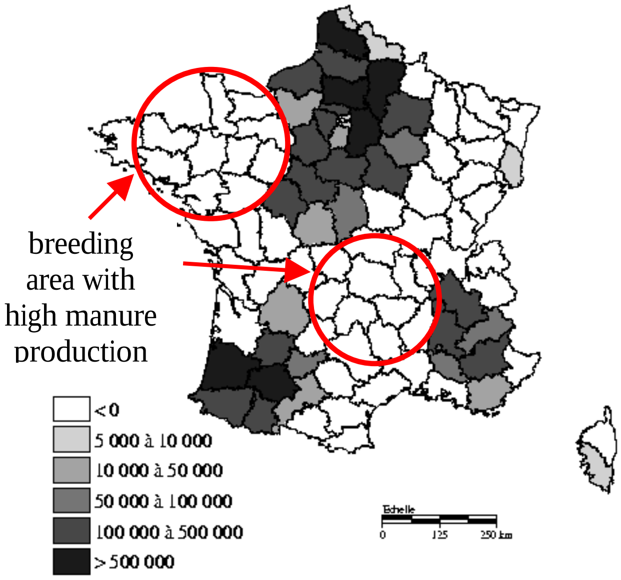
Fig. 1. Amounts of composts

A first plateau corresponds to the minimal duration of restoration for all soils. This stage is followed by a sharp fall that corresponds to the progressive reaching of the soils carbon content to the threshold fixed. The last stage corresponds to the quantities necessary to maintain these soils to the threshold fixed.

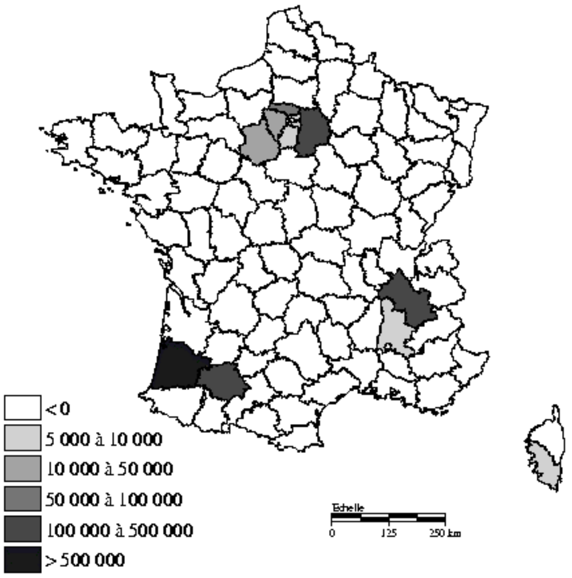
According to this estimate, the local use of manure would not be enough to restore the carbon stocks of the soils concerned, but would be enough to maintain the soils at a threshold of 1% of carbon.

Districts concerned

The maps 1 and 2 represent the departments which would be concerned by the need of composts in restoration (map 1) and in maintain (map 2).



Map 1 . Departments where composts would be necessary in addition of manure to restore at 1.5% the carbon rate of loamy soil showing a high erosion risk (t/ha/y)



Map 2 . Departments where composts would be necessary in addition of manure to maintain at 1.5% the carbon rate of loamy soil showing a high erosion risk (t/ha/y)

The results are confined in area where manure production is low. The regions concerned are :

- For restoration : Picardie, Aquitaine, Ile-de-France, Nord-Pas-De-Calais, Midi-Pyrénées and Rhône-Alpes,
- For maintaining : Aquitaine, Ile-de-France, Midi-Pyrénées and Rhône-Alpes.

Discussion

Comparison with the compost production

The compost production is distributed accordingly:

- Sludge compost : more than 110 000 tonnes (Carré, 1995),
- Green waste compost : 240 000 tonnes (ADEME, 1999),
- Biowaste compost : 33 000 tonnes (from ADEME, 2000),
- Mixed municipal solid wastes compost : 630 000 tonnes (ADEME, 2000).

The present production of compost would not be enough to restore the carbon stocks of the soils concerned. However after restoration it would be enough to maintain the soils at a threshold of 1%, 1.1%, 1.2%, 1.3%, 1.4% of carbon, but not at 1.5%. This threshold of 1.5% was demonstrated for the silty soils of South of France (Le Bissonnais and Arrouays, 1997).

Model accuracy

These estimates were made using the Hénin-Dupuis model, which is widely used in France, but fails to take into account a number of important variables and kinetic processes which require a multi-compartment model (Mary and Guérif, 1994). We recommend that this study be reviewed and new conclusions drawn based on the work currently being performed on bi-compartmental models (Mary and Guérif, 1994), or multi-compartment models.

Organic matter deficit

This study is based on the hypothesis that the soils exhibiting a high erosion risk and low organic matter content present a deficit of organic matter. This deficit can be compensated in different ways: crop system adaptation, modification of cultivation practices or exogenous input. But other actions can be engaged to reduce the erosion risk : installation of anti-erosion systems or modification of cultivation practices.

Conclusion

The objective of this study was to calculate the amounts of organic matter necessary to restore and maintain at a given level the organic matter content in soils exhibiting a high risk of crusting and erosion.

The results suggest that the amounts of manure locally available are inadequate to restore and maintain the soils concerned. For a threshold of 1.5%, 10 millions tonnes of compost would be necessary for restoration, and this declines after 40 years to 1.3 millions tonnes annually once the threshold of organic content is reached. In the light of such findings, it appears that composting has much potential for development in France. But only a very good quality of compost will be able to guaranty the future and commercial viability of this activity.

This estimates must also bear in mind the limitations of the model used as described above. Further improvements should include :

- Elaborating accurate references for the calibration of organic matter evolution model : long term field experiment (Houot et al, 1999),
- Improving database accuracy ,
- Developing more mechanistic models of organic matter evolution.

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Session II

Plant Nutrition and Productivity – Is Compost a Competitive Fertiliser?

INTRODUCTION

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Introduction

In the discussion about benefits of compost often the effect of compost as a fertiliser is mentioned. 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

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.

Concentration of nutrients and plant availability

The concentration of nutrients vary in a wide range (Table 1) depending on type of compost and type of raw material. Investigations of Boisch (1997) showed that especially biowaste-composts have a higher amount of nutrients as other composts.

Table 1. Limits of variation of total amounts and plant available amounts for P, K and Mg in composts

	Total amounts (mg/kg DM)	supply with 20 t compost/ha (kg/ha)	plant available amounts (mg/kg DM)	supply with 20 t compost/ha (kg/ha)
Phosphorus	1000-5000	20-100	200-2000	4-40
Potassium	5000-12000	100-250	1600-10000	32-200
Magnesium	1200-4000	25-80	100-600	4-15

The effectiveness of these nutrients in comparison to mineral fertilisation is depending on the type of compost and site-specific conditions. Therefore the effectiveness varies in a wide range, too. But all in table 1 listed nutrients have a higher ratio of plant availability as nitrogen. Ebertseder (1997) investigated the effectiveness of phosphorus from compost and showed that in a moderately acid soil it was up to 70 % of a mineral fertilisation but in a slightly basic soil it was only about 20 %.

A lot of studies showed increasing amounts of plant available P und K in soils after application of compost (e. g. Martins & Kowald, 1988, v. Fragstein et al., 1995, Hartl et al., 1998, Pinamonti, 1998). This is induced by high quantities of compost application, which is orientated at the N requirement of plants and because of the low N utilisation (approx. 10-20 %) high amounts of compost.

Effect of compost on yield

The most studies showed a positive effect of compost on yield.

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 the effect of mineral fertilisation (Fig. 1). 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 t/ha of fresh compost indicated a significant higher yield in comparison to mineral fertilisation.

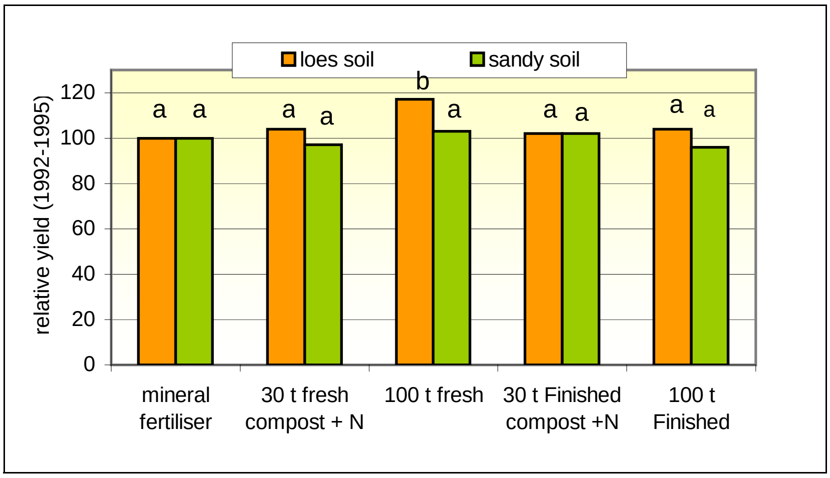

Fig. 1. relative yield over four years (1992-1995) at different compost treatments (after Petersen & Stöppler-Zimmer (1996))

Klasnik & Steffens (1995) investigated the effect of compost at different rates of application and different amounts of nitrogen supplementation in comparison to a recommended PK control (Fig. 2).

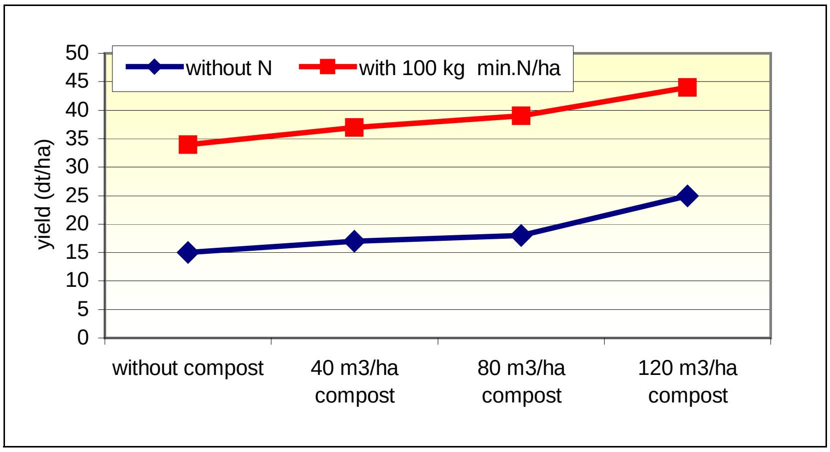

Fig. 2. Influence of compost with and without supplementary mineral N fertilisation on yield of Triticale (Klasnik & Steffens, 1995)

In the treatments with no nitrogen mineral fertilisation the yield increased from 1.5 to 2.5 t/ha with increasing rates of compost application. This increase in yield can be attributed to the effect of nitrogen. But even at the highest rate of compost application of 120 m^3/ha/y the effect of compost nitrogen is much less than the application of 100 kg/ha mineral N-fertiliser which increased the yield from 1.5 to 3.4 t/ha. They also showed that the application of compost could influence the quality of plants. Application of compost could increase the amount of crude protein from 10.6 % up to 13.2 % at different rates of application.

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.

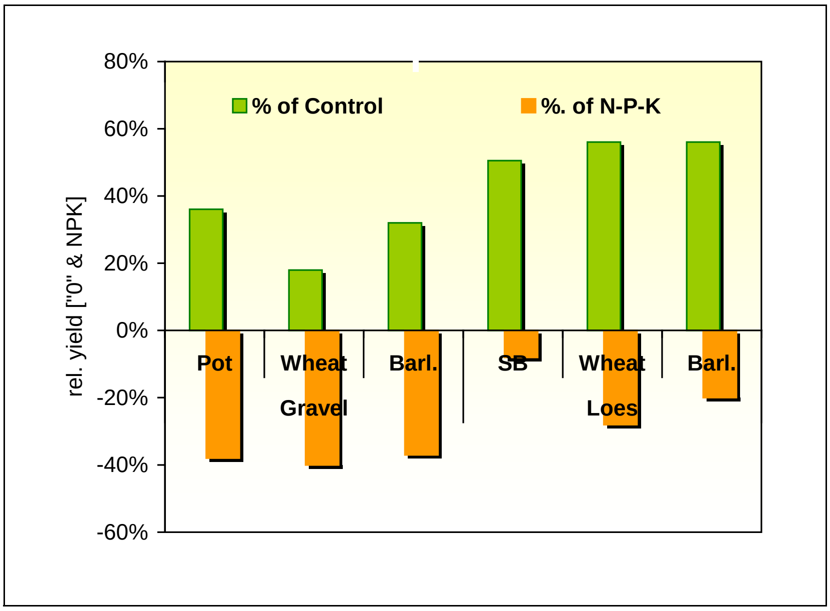

Fig. 3. Effect of compost on yield in comparison to an unfertilised control and a recommended NPK control (Pot: potato, Barl.: spring barley, SB: sugar beet)

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 t/ha/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 “Schotter” 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 compared with mineral fertilisers because of the different dynamic of fixation for nutrients.

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.

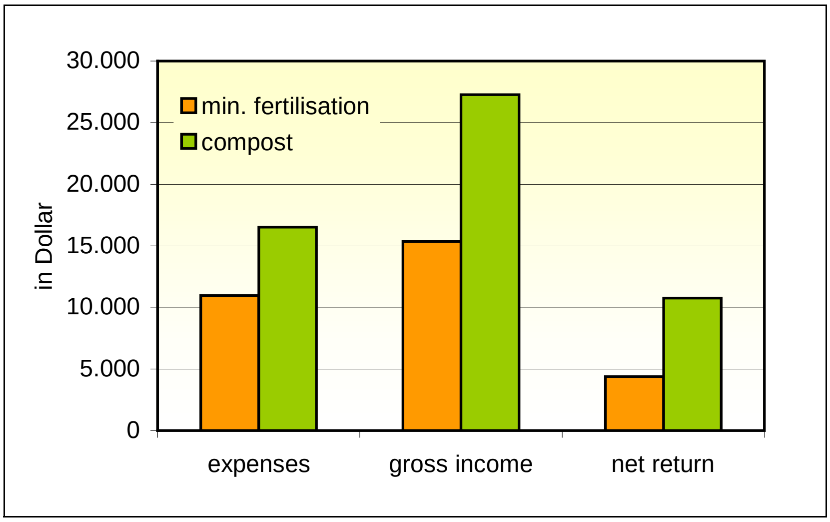

Fig. 4. expenses, gross income and net return of a tomato plantation with and without compost fertilisation (Steffen et al.,1994)

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 the 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 (Fig. 4)

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 partial negative because of high expenses for compost application and a miss of higher yield (Table 2).

Table 2. Net return (deficit) in £ at different treatments (HDRA Consultants, 1999)

	winter wheat	winter barley	oil seed rape
NPK	952	201	276
39 t compost + NPK	635	-42	89
117 t compost + P	-241	-424	-119
117 t compost + NK-reduced	16	-352	-155

Summary

The literature study shows that application of compost applies substantial amounts of nutrients to soils which vary in a wide range depending on type of compost and raw material. The utilisation of nutrients differs and depends on type of compost and site-specific conditions. Application of compost increases the yield and – in part – the quality of plants but compost is not a equivalent to mineral fertilisation. Together with a mineral-N supplementation compost can reach the same yield as a mineral NPK fertilisation. That suppose that compost is primarily to use as a substitute for phosphorus and potassium fertilisation.

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NUTRITION POTENTIAL OF BIOWASTE COMPOSTS

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Introduction

Composts are important nutrient carriers. In Germany alone, with an estimated annual production of about 8 Mt (equivalent to 5 Mt DM), their nutrient potential represents almost 10 % of the phosphate, potash and lime currently applied as mineral fertilizers, as well as about 2.5 % of the mineral-fertilizer N applied in the whole German agriculture. To make efficient use of these nutrient amounts, composts require the targeted application as secondary raw material fertilizers (Gutser, 1997). Therefore, it is the aim of this paper to show the effects of macronutrients contained in biowaste composts, and to deduce general strategies for their use.

Nutrient contents of biowaste composts

The composition of biowaste composts is highly variable, according to their respective raw materials, composting conditions, and regional origin. The ranges in Table 1 include those figures frequently cited in the literature.

Table 1. Nutrient content of biowaste compost – normal range -

	total content [% dry matter]	**soluble fraction [% total content]**
organic matter	27 – 60	
lime ($CaCO_3$)	2 – 11	
nitrogen (N)	1.0 – 1.8	1 – 7 *
phosphorus (P)	0.2 – 0.5	25 – 45 **
potassium (K)	0.4 – 1.3	75 – 100 **
calcium (Ca)	1.5 – 6.0	
magnesium (Mg)	0.2 – 1.1	
sulfur (S)	0.1 – 0.5	6 – 11 ***

* NH_4-N + NO_3-N ($CaCl_2$ extract) ** CAL extract *** SO_4-S ($CaCl_2$ extract)

Biowaste composts consist to 30 – 60 % of organic matter (Table 1), which is largely humified and stabilized, especially in mature composts. Due to their different raw materials, biowaste composts (higher percentage of kitchen refuse) tend to be richer in organic matter and nutrients than pure green waste composts (generally higher percentage of woody components). However, the line between these two types of compost is vague. A major criterion for the quality of organic matter is its C/N ratio (see 1.1.1 N transformation in the soil). With few exceptions that are due to high percentages of wood, fresh biowaste composts, at the onset of rotting, have already C/N ratios of less than 20, that drop to less than 14 in the fully rotted mature composts. In contrast, the variation in the C/N ratios of fresh green waste compost is much higher (up to 30 and above).

Also for mature green waste composts, the C/N ratio is generally significantly higher than for biowaste composts.

Composts contain variable amounts of lime (alkaline components). Thus, they have a generally slightly alkaline pH value (pH 7 to 8). The lime content of composts correlates with their degree of rotting, and with their Ca and Mg contents (Ebertseder, 1997), so that it can be assumed that a substantial part of the lime is generated during the composting process, by precipitation of CaCO3 and MgCO3 respectively. The contents of Ca and Mg are frequently related to the geogenically determined lime content of the soils in the area of the respective composting plant.

Because of their high contents of lime and especially of organic matter, composts have primarily to be considered as soil conditioners. In addition, they contain substantial amounts of nutrients (Table 1), so that a targeted application as fertilizer (multinutrient fertilizer) becomes necessary. When comparing the ratio of the total contents of nitrogen, phosphorus and potassium in biowaste composts (N / P / K » 1 / 0.2 / 0.6) with the ratio found in various crops, it becomes obvious that, in comparison to vegetables (on average N / P / K » 1 / 0.2 / 1.3; Fink et al., 1999) composts are relatively low in potassium but rich in phosphorus. This leads to the conclusion that, with crop-yield orientated fertilizer application to vegetables, the P content, next to the N content, normally constitutes the limiting factor for compost use. In mostly agricultural crop rotations (high percentage of grain crops), the nutrient ratio of compost matches that of the removed crop yields rather well.

Besides the total nutrient contents, nutrient solubility is of special importance, as it gives an indication for the immediate plant availability. Because of the different chemical reactions and binding forms involved, the solubility of the various nutrients differs strongly. Especially N is mostly present in very stable organic forms, with only a very small soluble fraction. On average, less than 5 % of the compost N consists of immediately plant available ammonium (NH4+) and nitrate (NO3-). However, 35 % of the phosphorus and almost all of the potassium (normally ³ 75 %) are soluble in the CAL extract.

The sulfur content of bio-waste composts range from 0.1 to 0.45 % DM. Similar to nitrogen, only a very small fraction thereof (normally < 10%) is present in immediately plant available form (SO4-S). Whereas for both sulfur and nitrogen, more than 90 % are normally incorporated in the organic matter, the N/S ratios of compost vary widely from 4 to 15 (Gutser and v. Tucher, 2000).

Nutrient effect

Compost application leads to humus accumulation in the soil. Consequently, to correctly assess the effect of the nutrients from compost, it is necessary to differentiate between a short-term effect in the year of application, and a long-term effect over the following years. This applies especially to those nutrients that are mostly present in organically-bound form (N, S).

Nitrogen

Nitrogen transformation in the soil

Generally, the nutrient effect of organic fertilizers depends largely on the transformation processes that take place in the soil after their application. This applies especially to nitrogen (N), for which its plant availability is tightly related to microbial transformations.

Primarily the degradability and C/N ratio of the organic matter determines, whether it comes to a net mineralization or immobilization of N after the application of an organic fertilizer. Mature composts still contain but only small amounts of easily transformable C compounds; their C/N ratio is normally 11 – 15, and thus only slightly above that of soils (ca. 10). With transformation processes on a low level, N immobilization and mineralization are almost in balance. The NH4 and NO3-N (Nmin) of mature composts can thus be considered as almost completely plant available in the year of application (Fig. 1).

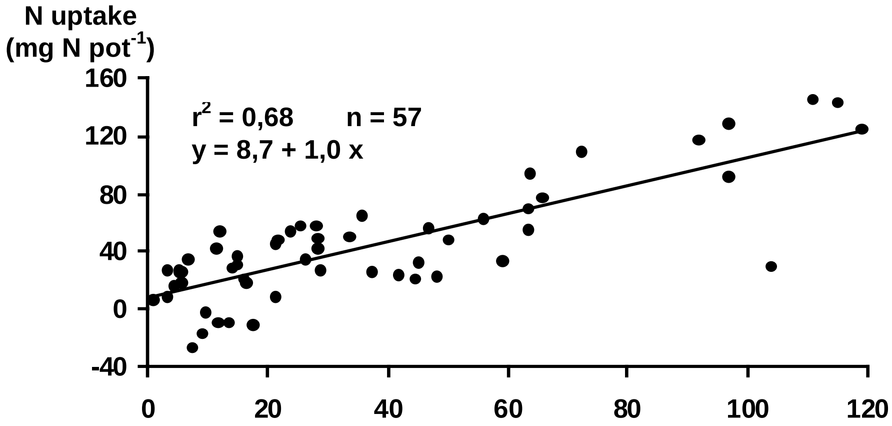

Fig. 1. Relation between N uptake of oats (difference to pots without N) and supply of soluble N with mature composts – pot trial (Ebertseder, 1997)

This does not apply to fresh and yet little stabilized composts. Most of their organic matter will still be transformed in the soil. This frequently leads to a net immobilization, so that less N is available for the plants than without compost application (possible yield reduction). Generally, remineralization on fertile soils is that rapid, that the yield of crops with a longer growing period is frequently not seriously affected. However, there are also fresh composts, especially those that contain a large portion of N-rich biowaste, which give a positive N effect that is clearly higher than that from average mature composts.

Parameters to estimate the possible N effect

To avoid N immobilization, especially in rapidly growing crops, and in order to calibrate the optimum supplemental mineral N-fertilizer application, suitable parameters are required by which the compost effect on yield and N supply may be quantified. For this purpose, biological methods to determine the degree of maturity (e.g. self-heating capacity, respiratory activity, enzymatic activity) are not very useful (Popp and Fischer, 1995, 1996).

A better parameter that can be used for all composts, independently of their degree of rotting, is the C/N ratio of the organic matter extractable by 2M K2SO4 solution (C/NK2SO4) (Ebertseder et al., 1995, 1996). It not only allows the differentiation between N supplying and N immobilizing composts, but also gives an indication for the N availability in the year of application (Ebertseder, 1997).

First results (Capriel et al., 1999) give rise to the expectation that it may be possible to substitute the relatively time-consuming chemical extraction methods, used hitherto to assess the plant available N potential, by simple and rapid spectroscopic analyses in the infrared range.

Short-term N effect

Independent of the degree of maturity, most of N from composts goes into the humus pool of the soil, either directly or via immobilization by microbial biomass. The immediate N effect in the year of application is very small, as confirmed by numerous field trials with a wide variety of crops on different sites. It often accounts for less than 5% of the applied compost nitrogen, and varies within a certain range with site- and crop-specific influences (vegetation period, soil tillage, etc.) (Fig. 2).

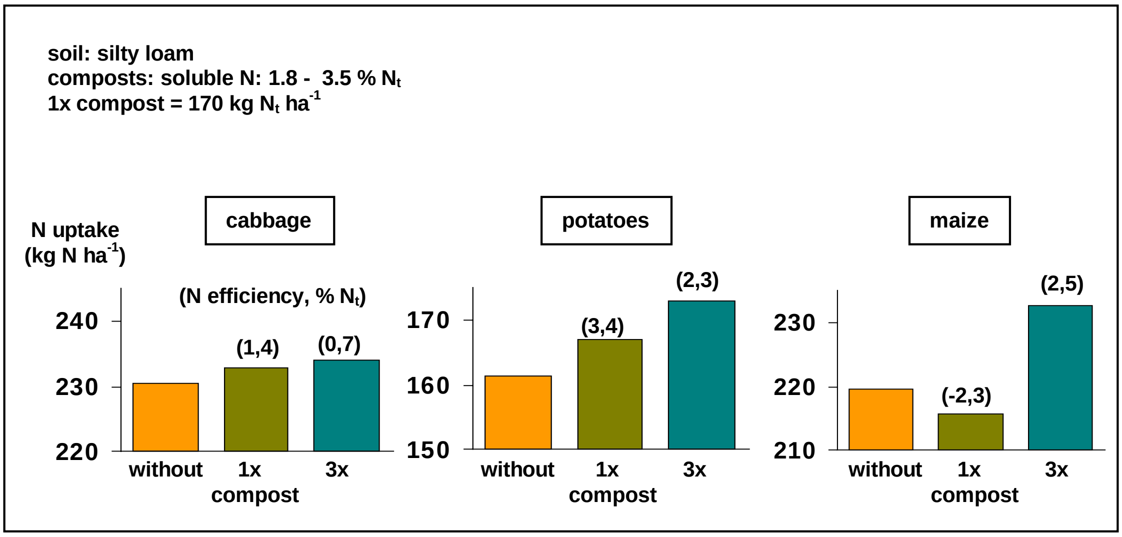

Fig. 2. Nitrogen efficiency of biowaste composts in the year of application – field trials – average of 2 composts and different additional mineral N levels (data from Popp, 1997, and Ebertseder, 1997)

Composts with a high percentage of green cuttings or garden waste (tree cuttings), under similar conditions for composting, generally give a slightly lower N effect than composts with a high percentage of bio-wastes (Scherer et al., 1996). Normally, a supplemental mineral fertilizer application has but little effect on the availability of the compost nitrogen. Also the combination of annual applications into one application for several years, gives no advantages for a better N utilization (% of supplied N). However, more compost N is then available for the plants in the year of application (Fig. 2, "3 x compost"), that has to be taken into account when calculating the mineral fertilizer supplement.

Possibilities to optimize the N utilization by the crops, constitute the choice of application date and the form of incorporation into the soil. Microorganisms and plant roots compete for nitrogen, that is normally the limiting growth factor. Therefore, strategies to place the compost short before or to the growing period to the crops, or to reduce the contact between compost and soil (application on the soil surface), offer the advantage of a slightly improved N utilization (up to about 10 %) that is, however, still much lower than that of mineral fertilizer (ca. 60 – 80 %).

Long-term N effect

Due to the small N effect in the year of application, more than 90 % of the compost nitrogen remains in the soil (increased soil N content). Already in the first consecutive year, the residual effect is only marginally different from the N release from soil organic matter (1.5 to 3.5 % per year, acc. to site). The site- and management-specific mineralization rate, both for soil nitrogen and compost nitrogen applied in a single year, is not increased by continuous compost application for several years (Table 2). The immediate effect of a compost incorporation on the net mineralization of soil nitrogen (reduced mineralization rate due to increased immobilization) is also not affected by a continued previous fertilizer application.

Table 2. Nitrogen mineralization in soils after different long-term fertilization, with and without the additional incorporation of biowaste compost (BWC) – Incubation trial in Mitscherlich pots; incubation: 296 days; 1 x compost = mean 170 kg N / ha×a (acc. to Ebertseder, 1997)

long-term fertilization (20 years)	N content soil %	N mineralization without BWC $\% N_t$	with additional BWC $\% N_t$
without N	0.10	3.3	1.7
mineral N	0.10	4.5	2.3
1 x compost	0.17	3.5	1.4
2 x compost	0.19	3.3	2.2

Generally, the N mineralization from organic matter (N release) is stronger on light sandy soils than on heavy soils. This is connected with a stronger compost transformation in the years following application. The soil type (e.g. sand, loam) and its relative mineralization rate have therefore, next to the application rate, the strongest effect on the enrichment of soil N by long-term application of compost, provided that climate, weather and crop management remain unchanged.

Long-term compost application on loamy soils, thus leads to a higher N accumulation and to a slightly slower increase in the N release than on sandy soils (Fig. 3). With increasing length of time, the N accumulation in the soil asymptotically reaches a maximum. Half of this maximum accumulation is reached after about 20 years on sandy soils, and after about 30 years on loamy soils.

An almost complete equilibrium between N supply and N mineralization (graph almost parallel to x-axis) is only reached after about 60 years (Fig. 3). This means that only after a relatively long period of time, the N amount annually released from the enriched soil pool (available for plants and N losses), becomes comparable to the annual supply.

compost supply: 100 kg N_t ha^{-1} a^{-1}

mineralization rate:	Year:	1	2	≥ 3
	sand:	8 %	4 %	3,5 %
	loam:	8 %	3 %	2,5 %

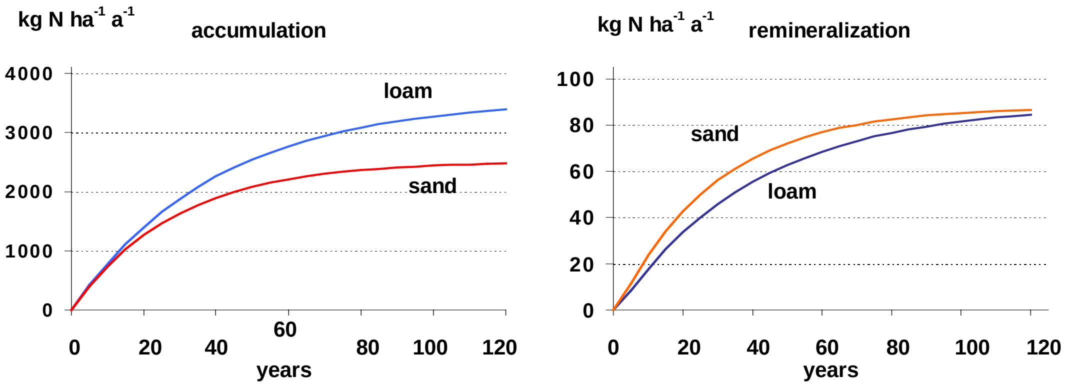

Fig. 3. Nitrogen accumulation and remineralization in different soils by long-term compost application – model calculation according to Gutser and Claassen (1994)

The significant increase in the N release from the soil, that becomes apparent in the model calculations, is confirmed in field trials already after a few years by an increased N uptake by the crops (Fig. 4). In accordance with N uptake the total N utilization increased with time, too (evaluation of the total period). But the N utilization in individual years and for individual crop rotations remains almost constant (mean < 1.5 % per year).

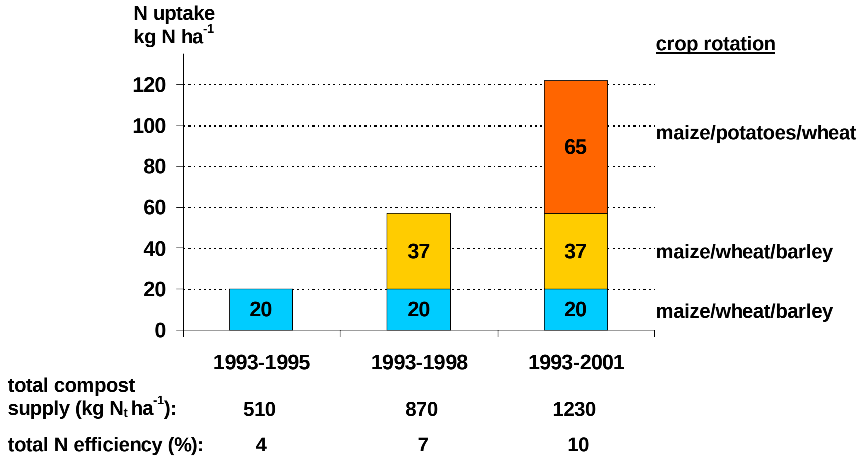

Fig. 4. Nitrogen effect of biowaste compost over a period of 3 crop rotations (9 years) - N uptake: difference to plots without compost

N mineralization is almost impossible to control and difficult to calculate. It coincides only partly with the N demand of the crops. A rather substantial amount of N is mineralized outside the vegetation period and is thus prone to leaching. It is therefore unavoidable that an enrichment of the soil with organic matter increases also the N-loss potential. This is confirmed by a lysimeter experiment, conducted in Weihenstephan (Fig. 5).

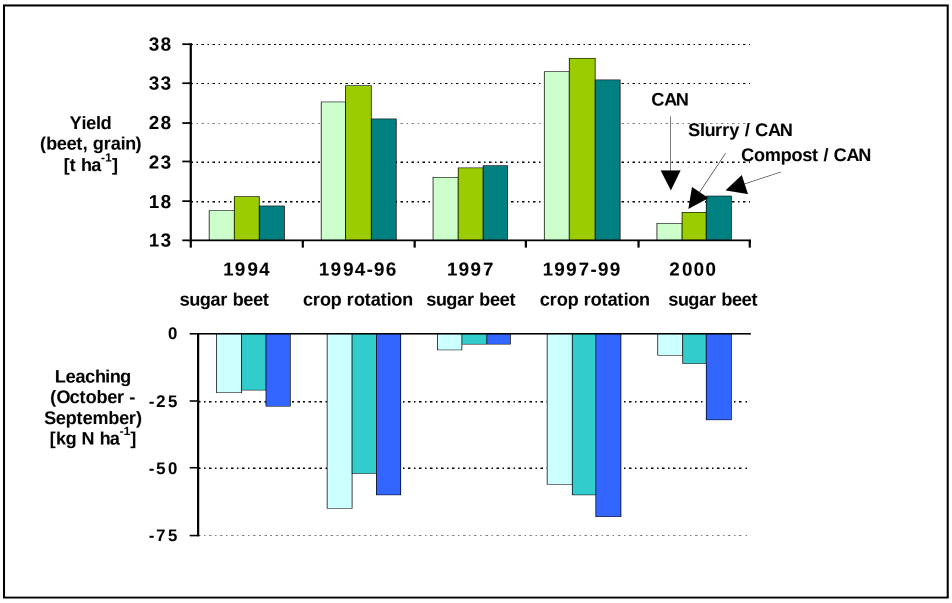

Fig. 5. Long-term nitrogen effect of biowaste compost and cattle slurry in a lysimeter trial (soil: silty loam; Crop rotation: sugar beet – winter wheat – winter barley (+ cover crop); mean precipitation: 810 mm y^{-1})Trial started in 1980 with uniform slurry/calcium ammonium nitrate (CAN) application. Since autumn 1993, biowaste compost every 3rd year prior, to sugar beet Fertilizer treatments (kg ha^{-1}): cattle slurry (120 N annually), biowaste compost (360 N every 3rd year) with CAN (60 N annually); CAN (mean 160 N annually).

Long-term compost application showed a good yield effect, also when compared to mineral fertilizer (calcium ammonia nitrate, CAN) and slurry, but simultaneously increases the N-leaching risk under the humid site-specific conditions of Weihenstephan (Fig. 5). Especially after the third compost application in September 1999 (at a rate of 360 kg N/ha), it was found that 20 kg N/ha more were leached until September 2000 than under the control treatments.

Strategies for compost use, which are meant to be compatible with the principles of sustainable agriculture and environmental needs, have to take into account this rise of the N leaching potential. It is invariably connected with compost application, and have to restrict the permissible annual N load. This generally excludes the possibility, even in the long run, to produce maximum yields by compost application alone. High yields always require an adequate mineral fertilizer supplement.

Phosphorus

About 35 % of the phosphorus in composts is present in soluble form (CAL extract) and about 20 % is bound organically (Cabrera et al., 1991; Ebertseder, 1997; Traoré et al., 1999). The organic P fraction within total P does not increase during the composting process. However, depending on the composting conditions (temporarily anaerobic) and on the composition of the original materials (percentage of domestic and kitchen waste), there is an increase in the share of difficultly soluble inorganic P compounds (Ca/Mg phosphates, Fe/Al phosphates) (Traoré et al., 1999). The P-transformation processes during composting, seem to be almost similar to those taking place in the soil with mineral-fertilizer P. The products of these transformation are rated as long-term fully plant available. Microbial processes (immobilization, mineralization) play only a minor role for the P availability of compost (different from N).

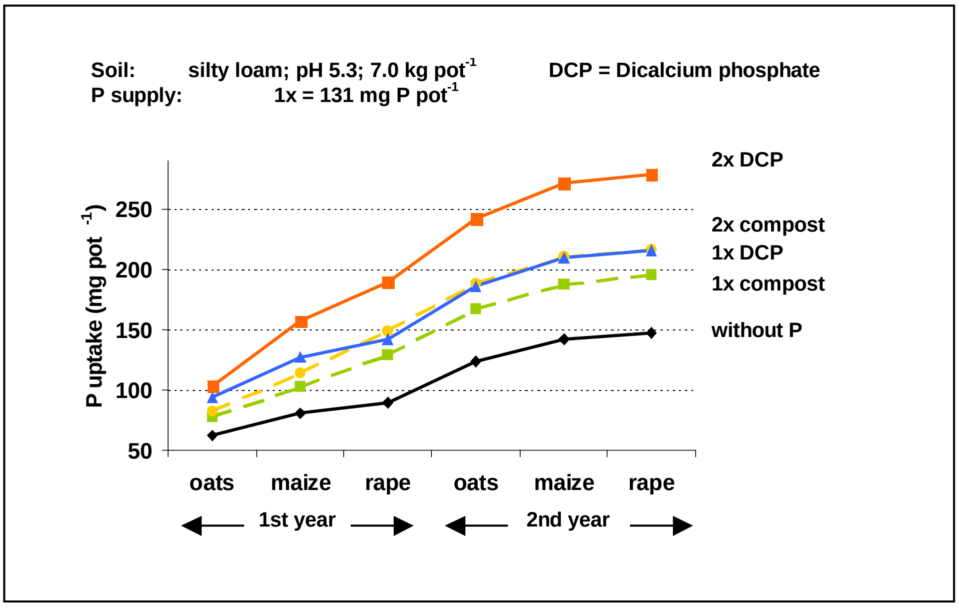

Fig. 6. P effect of biowaste compost (35% of Pt CAL soluble) and dicalcium phosphate (DCP) – pot trial, trial period 2 years, rotation: oats-maize-rapeseed (Ebertseder, 1997)

All in all, composts show a relatively good P-fertilizer effect, as confirmed for example by the results of a pot trial with biowaste compost (Fig. 6). However, compared to mineral fertilizers, the effect of compost phosphates is frequently slower, and their plant availability in the first years after the application thus lower. It should be noted that there are also large differences in the solubility of the various mineral fertilizers, and thus their plant availability on different soils (pH value, sorption conditions).

It is often not possible to directly establish the P effect of composts by field trials, as other factors (N availability, physical soil-condition) have a stronger effect on the yield development than phosphate, which is normally present in the soil in sufficient quantities. Sites on which compost has been applied for several years, often show an increased soil content of soluble phosphate, depending on the compost supply (Fig. 7). This observation has been made in many trials (Diez and Weigelt, 1980, Bischoff, 1988, Diez and Krauss, 1997) and confirms the high long-term P availability. Since plants live predominantly from the P pool of soil, it is suitable to fully include compost P in the calculation of the fertilizer rate, similar to P from farm-yard manure and mineral fertilizers.

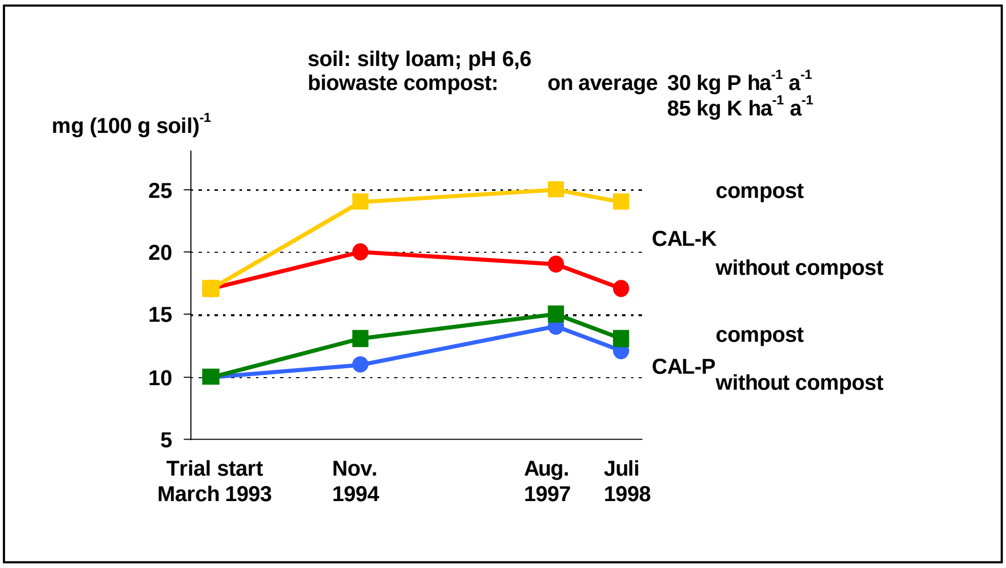

Fig. 7. Effect of biowaste compost on nutrient status of soil (CAL-Extract) – field trial -

Potassium

Normally, more than 75 % of the potassium in composts is soluble (CAL extract), so that the same good plant availability can be expected as for potassium from mineral fertilizers. The potassium in composts can thus be fully inserted into the calculation of the fertilizer requirement. Soil analysis also shows increased values for CAL-soluble K after compost application (Fig. 7).

Sulfur

Similar to nitrogen, the effect of sulfur from organic fertilizers is principally controlled by microbial transformation processes in the soil (mineralization, immobilization). Therefore, both the availability of N and S is widely governed by the same laws.

Short-term sulfur effect

The sulfur effect in the year of compost application is determined (i) by the SO4 S content, and (ii) by the C/S ratio. As well as nitrogen, sulfur is immobilized by incorporation into the microbial biomass, when easily degradable organic matter poor in S, is transformed in the soil. Sulfur immobilization is to be expected after the application of organic fertilizers with a C/S ratio of 80 and above.

Composts normally have C/S ratios < 75 (Gutser and v. Tucher, 2000). A significant immobilization of the applied SO4 sulfur is therefore not to be expected. The Smin fraction accounts for 5 to 10 % of the total sulfur content (see Table 1) and consequently the short-term utilization of the compost S by the plants is of a similar magnitude. In one-year pot trials (see also Gutser and v. Tucher, 2001) high additional yields were obtained with SO4 containing mineral fertilizers, but not with biocompost or farmyard manure (Fig. 8). The sulfur applied via organic fertilizer gave at best a mineral-fertilizer equivalent of about 5 to 15%.

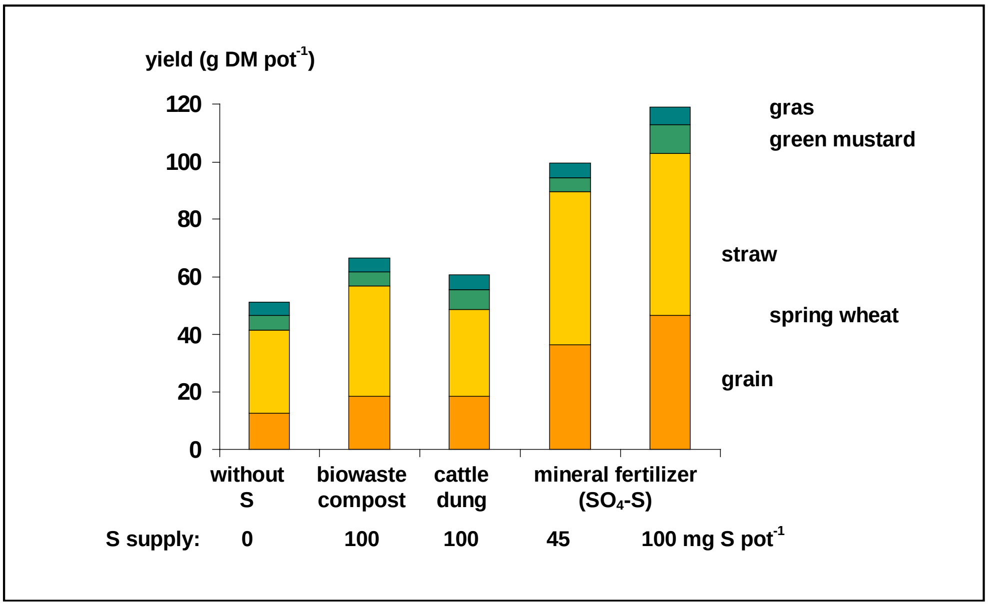

Fig. 8. Short-term sulfur effect of biowaste compost in comparison to mineral fertilizer and farm-yard manure – Yield of spring wheat, forage mustard and ryegrass pot trial, fertilizer: 45 and 100 mg S / Mitscherlich pot, resp.

Long-term sulfur effect

Ca. 90 % of the compost sulfur is organically bound. This fraction is not initially plant available in the year of the compost application. Together with the organic matter and similar to nitrogen it accumulates in the soil with continuing compost application, thereby increasing the capacity for N release (Fig. 9).

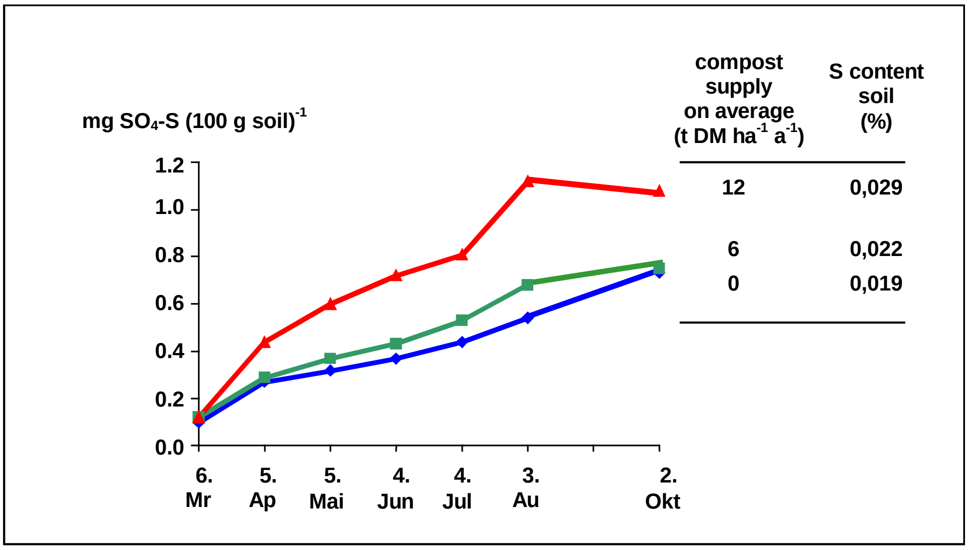

Fig. 9. Sulfur mineralization in long-term biowaste compost amended soils incubation experiment with surface soils from a 7 year field trial

The sulfur released from the soil organic matter can be used by the plants and does thus contribute to reduce the fertilizer S requirement. On a soil to which compost had been applied for 25 years (mean 10 – 12 t DM ha-1 a-1; S content: without compost 0.019 %, with compost 0.026 %), an optimum mineral-fertilizer S application to spring wheat resulted in yield increases of up to 12 % only, compared to 51 % on the control soil (pot trial; Gutser and v. Tucher, 2000). Whether the plants' S demand is met, depends not only on the amount of mineralized S, but also on the date on which it is released. Compared to N mineralization, S mineralization depends more on the temperature (Gutser and v. Tucher, 2001). Normally, it begins later (higher soil temperature). Therefore, the release from the soil S-pool can mainly be used by crops with a long growing period (e.g. sugar beet, maize, cabbage) and a late S demand, or by crops growing later in the year (second or third crops). S mineralization does not contribute significantly to meet the demand of crops with a high S demand in spring, especially not after a wet winter (S leaching).

Conclusions for compost use

For a removal-orientated fertilization, phosphorus and potassium from compost can be (at least in the long term) fully incorporated into the calculation of the fertilizer rate. To meet an average P demand of 25 – 30 kg P ha-1 a-1, about 7 – 8 t DM compost, equal to approx.. 120 kg N ha-1 a-1 are required. This N amount also represents the long-term permissible maximum quantity of compost, to curb N accumulation in the soil, and to restrict losses to the unavoidable.

The minor N effect in the year of application, and the hard-to-calculate N release from the soil N-pool, necessitate the targeted supplemental application of mineral fertilizer, in order to optimize crop yield and quality. Also this is feasible at a maximum compost application rate of 120 kg N ha-1 a-1. With increasing soil N accumulation and N release from the soil, the supplemental fertilizer applications can be reduced, especially in slowly-growing crops.

A significant contribution of compost to the S supply of the crops, can only be expected after long-term compost application and for slowly-growing crop species. On S deficient sites, a maintenance S-fertilization is normally required.

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THE LONG-TERM VEGETABELE PRODUCTION EXPERIMENT: PLANT GROWTH AND SOIL FERTILITY COMPARISON BETWEEN FERTILIZER AND COMPOST-AMENDED SOILS

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Abstract

A paired comparative study of compost versus conventionally-fertilized vegetable plots has been conducted for 11 years in a sandy loam soil near Truro, Nova Scotia; likely the longest study of its kind in Canada. The fertility treatments have been applied annually to six rotation plots planted with six to eight different vegetable crops. Compost and fertilizer applications have been based on the results of soil sampling and the Nova Scotia Soil Test Recommendations, and assuming 50 or 100% availability of the total N in the mature composts or fertilizers, respectively. The composts consist of animal manure, food waste, yard waste and straw or racetrack manure bedding. Marketable yields have been taken annually since 1990 and the plant tissue samples have been analysed for macro- and micronutrients, while soils have been sampled for pH, organic matter and Mehlich-3 extractable nutrients since 1994. This paper reports the results of the 1999 and 2000 cropping years.

Crop yield response was inconsistent between the two amendments; yields of tomatoes and broccoli varied from year to year. The fertilized plots, however, produced higher bean yields and numerically higher carrot and pepper yields, while the compost-amended plots produced higher onion yields in both years. There were few significant effects of treatments on plant tissue content; only Fe and B were higher in the organically-amended plant leaves in 1999. Of 19 soil parameters evaluated, the cation exchange capacity and the Mehlich-3 extractable Ca, Mn and Pb content of compost-amended soils were higher following the harvest in both study years. This six crop rotation study ended in 2001; in addition to the above parameters, emphasis is directed to soil biochemical changes which may have occurred from the continuous agronomic applications of the compost or fertilizer.

Introduction

Numerous authors from various countries have examined different characteristics of vegetable crops whose soils were amended with compost and/or fertilizer. Ozores-Hampton and Obreza (2000) wrote an extensive review describing the use of composted waste on Florida vegetable crops. In Scotland, Purves and Mackenzie (1973) evaluated Cu, Zn and B uptake by garden vegetables from municipal compost applications in three successive years; as expected, the vegetables responded differently to the compost treatments. Vogtmann et al. (1993) described the effects of composts on the yield and quality of some vegetables in Germany. Compared with chemical fertilizers, compost treatments lowered vegetable yields the first two years, but yields did not differ after the third year of fertility applications. Generally, composts positively affected food quality and storage performance while reducing nitrates and improving the nitrate to vitamin C ratio.

The quality of conventionally and organically grown foods have been reviewed by Woese et al. (1997). They identified “some differences in quality between products” of the two fertilization systems. More recently, in their review of the literature, Brandt and Molgaard (2001) stated “organic plant foods may in fact benefit human health more than corresponding conventional ones”. However, most previous studies were somewhat flawed since they were short-term and did not compare identical cultivars grown in the same soil type with similar soil and crop management practices. Also, many projects used high fertility soils or those with a history of fertilizer use or agronomically inappropriate rates of compost or fertilizer. Some studies have evaluated the differences in yield as well as quality, while others have examined differences in nutrient composition.

Past studies on peppers, cabbage, carrots, beans and broccoli, crops used in this study, have produced mixed results. Roe et al. (1997) grew peppers and cucumbers in a sandy soil supplemented with compost or fertilizers; yields were usually higher when compost was combined with fertilizer, while pepper leaf P, K, Ca and Mg increased and Cu levels decreased in plots amended with only compost. Reider et al. (2000) compared four composts with dairy manure and conventional fertilizer in a three-year rotation (which included peppers) and showed no significant yield differences among treatments for the three years; the authors used a 40% N availability factor for compost. In a three-crop vegetable rotation and a comparison of four organic amendments with chemical fertilizer, Blatt and McRae (1998) found equivalent marketable yields of cabbage and carrot from organic or fertilizer plots, but green bean yields were higher from 17-17-17 fertilizer. Treatment effects on soil and foliar nutrient contents varied with the element evaluated. Baziramakenga and Simard (2001) and Wen et al. (1997) compared compost fertilization with mineral fertilizers for snap bean and other crops, whereas, Buchanan and Gliesman (1990) evaluated broccoli production. These three studies emphasized P use efficiency or P uptake.

Warman and Havard (1996,1997,1998) conducted an extensive comparison of four vegetables grown organically and conventionally using non-rotational practices between 1990 and 1992. At the end of the first year of that study it was decided to maintain one set of six plots using compost and inorganic fertilizer treatments in a long-term (six year) vegetable crop rotation. The author has reported the experimental results for 1995 and 1996 (Warman, 1998) and for 1997 and 1998 (Warman, 2000). This paper reports on the 1999 and 2000 production years, with the objectives to compare the yield and nutrient content of different vegetables grown in a crop rotation system using either composted farmyard manure or commercial fertilizer, and evaluate the extractable nutrient content, pH, total C and N, and CEC of the treated soils.

Materials and Methods

This field trial began in 1990 and has continued on the same site to this date. A Pugwash sandy loam (Humo-Ferric Podzol) in Lower Onslow, N.S. was selected because the site had no history of inorganic fertilizer or pesticide use. The site was used to grow cabbage and carrots in 1990 as part of the study documented in Warman and Havard (1996, 1997). Table 1 lists the crops grown in the plots for the last eight years. Each plot has an area of 11 m2 and all the crops are planted into four rows/plot of 2.25 m long with a 1.2 m wide separation between plots. Each year an equal number of seeds or transplants were planted into each paired compost and fertilizer plot. Since the beginning of cropping, the six plots of each of the two treatments have been assigned to alternate plot areas.

Fertility amendments for each crop species were applied to the soil according to the Soil Test Recommendations of the Nova Scotia Department of Agriculture and Marketing (Table 2). Lime was applied to half the plots in 1998 to bring the soil pH of all plots to about 6.5; lime has not been applied since that time. The conventional method of growing the six types of vegetables followed the recommendations of the Vegetable Crops Guide to Cultivar Selection and Chemical Pest Control for the Atlantic Provinces (OCIA, 1990; Publication #1400A). Initially, organic vegetable production followed the Organic Crop Improvement Association guidelines; however, after 1992, only organic fertilization with compost was maintained and insects were controlled using rotenone, pyrethrum or Bacillus thuringensis powder or liquid formulations. Plots were hand-weeded or rototilled; fungicides were not used.

Table 1. Crop rotation (1993-2001) of the eleven crops among the six plots at the study site

	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	POT	CAR	SWC	BRO/ CAU	ONI	*TOM*	BEA	CAR	CAU/ B.SP
2	CAR	ONI	SWC	TOM	BEA	CAR	PEP	BRO/ B.SP	TOM
3	ONI	SWC	TOM	ONI	BRO/ B.SP	PEP	CAR	BEA	ONI
4	BEA	SWC	ONI	TOM/ PEP	CAR	BEA	TOM	ONI	PEP
5	BRO	SWC	CAR	BEA	TOM	ONI	BRO/ CAB	PEP	CAR
6	CAB	TOM	BEA	CAR	PEP	BRO/ CAU	ONI	TOM	BEA

BEA: Beans
BRO: Broccoli
B.SP: Brussels Sprouts
CAB: Cabbage
CAR: Carrots
CAU: Cauliflower
ONI: Onions
PEP: Peppers
POT: Potatoes
SWC: Sweet Corn
TOM: Tomatoes

Table 2. Quantities of Amendments Applied to the Plots in 1999 and 2000

Crop	**Moist YMFC** (Mg ha^{-1})	**NPK Fertilizers (kg ha^{-1})** N	P_20_5	K_20
Tomatoes	25	60	85 - 225	30 - 60
Carrots	25	60	60 - 85	30
Peppers	34	80	60 - 85	30 - 50
Beans	13	30	50	0 - 30
Onions	50	120	150 - 225	30 - 50
Broccoli/ Cabbage or Br. Sprouts	63	150	150 - 225	30 - 50

The compost was made the year prior to its application using the aerated static pile method with a combination of chicken manure, food waste, grass clippings/weeds, and straw/racetrack manure bedding (designated YMFC). The mature compost was analysed for total N using a LECO CNS Analyzer and applied at rates appropriate to each crop assuming 50% availability of the N during the growing season. The analysis of the compost has varied slightly from year to year; the nitric acid procedure for compost digestion and ICP analysis is reported in Warman and Havard (1997). Based on the average values of the compost used in the two years, some chemical properties of the compost are shown in Table 3 (elemental analysis in g kg-1 or mg kg-1 on a dry weight basis); in addition, the YMF compost was 44% solid with a pH of 6.84.

Table 3. Mean Elemental Analysis of the YMFC Compost used in the Study (dry weight basis)

	YMFC g kg^{-1}		YMFC g kg^{-1}		YMFC mg kg^{-1}
C	318	Mg	1.22	Cu	77
N	25.3	S	4.26	Zn	107
P	13.6	Na	5.83	B	39
K	13.4	Fe	6.03		
Ca	36.1	Mn	1.32		

Marketable fresh weight yields were taken annually from each plot at maturity, while leaf/petiole tissue samples were taken at flowering, fruit-set or root elongation. Five mature plant leaves from each row (20 in total) were sampled from each vegetable plot each year. Tomatoes, peppers and snap beans were harvested 6-10 times until the frost in the fall. Soil samples were taken in September of both years at the 0-15 cm depth. Plant tissue samples were washed with water, air dried for 48 hours, oven dried at 65C for 48 hrs and ground in a Wiley Mill to pass through a 1.0 mm stainless steel sieve. Tissue was digested in nitric acid and analysed by ICP for macro-, micro-, and trace elements, except N, which was analysed using a CNS analyzer (Warman and Havard 1997, 1998). After harvest, soil samples were taken from each plot from the 0 to 15 cm layer using a stainless steel probe. The soil was extracted with Mehlich-3 solution and analysed by ICP. Soil samples were also evaluated for pH, total C and N, and cation exchange capacity (CEC) using the calcium acetate saturation procedure.

Treatment results for crop yields, tissue content and extractable soil elements were statistically analyzed using a paired, two-tailed t-test or ANOVA at $p<0.05$.

Results and Discussion

Crop yield response was inconsistent between the two amendments; yields of tomatoes and broccoli varied from year to year (Table 4). The fertilized plots, however, produced higher bean yields and numerically higher carrot and pepper yields, while the compost-amended plots produced higher onion yields in both years. I noted that the % of Class A carrots, which had shown a higher % for organic carrots in 1997 – 1999, changed in 2000. Onion yields, however, were greater in the organic plots, as they had been in 1997 and 1998 (Warman, 2000).

Table 4. Fresh Crop Yields (kg) from the Six Paired Rotation Plots

		1999			2000	
Plot #		**NPK**	**Compost**		**NPK**	**Compost**
1	Beans*	15	14	Carrots % Class A	13 87	13 83
2	Peppers	17	15	Broccoli	1.7	1.0
3	Carrots % Class A	25 70	22 86	Beans*	11	9
4	Tomatoes	33	42	Onions**	12	14
5.	Broccoli Cabbage	3 10	4 9	Peppers	7	6
6	Onions**	16	21	Tomatoes	13	11

* Yields significantly higher with the NPK treatment

**Yields significantly higher with the compost treatment

There were few significant effects of treatments on plant tissue content (Tables 5 and 6); of the essential plant nutrients, only Fe and B were higher in the organically-amended plant leaves in one year (1999). Although the edible portion of the crops were not evaluated the last few years of the study, we have found a positive correlation between leaf tissue and edible portions of carrots (Warman and Havard, 1997) and other crops. Therefore, based on mineral analysis, our results do not support the belief that compost-grown vegetables are more nutritious.

Of 19 soil parameters evaluated, the CEC and the Mehlich-3 extractable Ca, Mn and Pb content of compost-amended soils were higher following the harvest in both study years (Tables 7 and 8). I noted that the compost-amended plots also had higher levels of Mehlich-3 Cu, Zn, and B in 2000, and this was the first year since 1996 that C was not significantly higher in the compost-amended plots. The 11 years of continual compost or fertilizer applications have significantly reduced the original differences in soil fertility between the plots so there are fewer differences between the treated soils in N-P-K but more differences between the soils in extractable micronutrients. Furthermore, compared to the composts produced and used in 1990-1992 (Warman and Havard, 1997), the compost we are now making and using is of higher nutrient quality, probably due to the higher nutrient feed stocks we are using (more weeds and food wastes), and the improvement in our ability to make a better quality compost.

Table 5. Leaf tissue analysis of macronutrient (g kg^{-1}), micronutrient and trace elements (mg kg^{-1}) of the NPK fertilizer and YMFC compost plots from 1999

	C	**N**	**P**	**K**	**Ca**	**Mg**	**S**
Carrot-NPK	420	27.0	2.00	1.85	4.9	3.13	4.67
Carrot-YMFC	406	22.2	2.01	1.09	8.9	3.32	6.17
Broccoli-NPK	391	35.3	2.25	7.05	10.6	2.95	6.48
Broccoli-YMFC	411	27.4	3.11	8.95	11.1	2.70	5.54
Pepper-NPK	408	49.3	3.19	1.88	13.7	6.40	4.70
Pepper-YMFC	395	53.5	2.55	1.86	15.2	6.55	5.09
Bean-NPK	406	32.9	1.71	1.17	11.0	4.75	3.26
Bean-YMFC	415	31.5	1.81	1.19	11.6	5.02	3.11
Tomato-NPK	414	29.6	1.86	0.95	13.0	5.72	6.41
Tomato-YMFC	412	31.8	2.52	1.16	13.8	5.30	5.90
Onion-NPK	411	36.3	2.63	7.63	7.4	4.25	6.43
Onion-YMFC	414	32.3	2.37	9.45	6.8	4.82	6.77
p-value	0.929	0.341	0.618	0.286	0.141	0.589	0.775

	Fe	**Mn**	**Cu**	**Zn**	**B**	**Cr**	**Na**	**Pb**
Carrot-NPK	140	60	8.4	40	27.7	1.3	1835	1.5
Carrot-YMFC	160	64	7.1	32	30.6	1.7	2626	9.0
Broccoli-NPK	60	42	8.1	31	11.6	1.0	2084	4.6
Broccoli-YMFC	70	45	9.9	27	25.9	2.4	1332	11.3
Pepper-NPK	70	48	4.9	49	18.2	1.7	54	11.9
Pepper-YMFC	90	36	8.9	25	19.1	1.7	42	2.5
Bean-NPK	60	43	6.5	38	13.7	1.0	57	1.2
Bean-YMFC	90	42	7.1	25	16.2	1.0	45	2.1
Tomato-NPK	40	36	4.7	25	9.6	1.2	2065	1.5
Tomato-YMFC	70	40	9.3	37	17.1	1.6	1967	3.1
Onion-NPK	90	27	5.6	18	8.7	1.3	515	0.9
Onion-YMFC	140	28	9.0	31	16.6	1.2	1024	0.9
p-value	0.005	0.886	0.066	0.537	0.031	0.201	0.758	0.654

Table 6. Leaf tissue analysis of macronutrient(g kg^{-1}), micronutrient and trace elements (mg kg^{1}) of the NPK fertilizer and YMFC compost plots from 2000

	C	**N**	**P**	**K**	**Ca**	**Mg**	**S**
Carrot-NPK	414	27.4	2.03	12.7	10.2	2.95	4.42
Carrot-YMFC	426	25.7	1.45	10.4	7.7	2.97	3.59
Broccoli-NPK	401	35.7	1.05	13.0	14.0	27.0	1.17
BroccoliYMFC	414	37.4	1.43	15.0	19.0	34.0	1.35
Br.Sprout-NPK	414	49.5	1.28	3.3	8.0	1.39	3.27
Br.SproutYMFC	399	51.5	2.02	3.9	8.5	1.38	5.59
Pepper-NPK	408	32.1	1.23	14.1	16.0	6.17	5.29
Pepper-YMFC	413	31.7	1.50	14.7	15.6	5.83	6.75
Bean-NPK	417	29.9	1.41	7.0	9.8	3.16	1.77
Bean-YMFC	414	31.7	2.20	7.3	10.5	3.06	3.33
Tomato-NPK	419	36.8	1.50	10.0	16.2	5.85	6.01
Tomato-YMFC	412	35.2	1.50	10.4	17.3	5.08	6.93
Onion-NPK	426	34.8	1.24	6.3	5.6	1.47	2.58
Onion-YMFC	431	32.6	1.87	6.8	5.3	1.54	2.18
p-value	0.725	0.938	0.133	0.559	0.521	0.727	0.135

	Fe	**Mn**	**Cu**	**Zn**	**B**	**Cr**	**Na**	**Pb**
Carrot-NPK	78	22	7.5	17	20.0	0.5	2398	4.8
Carrot-YMFC	69	20	5.1	12	12.8	0.5	1242	3.1
Broccoli-NPK	178	32	13	40	15	1.3	640	6.5
BroccoliYMFC	167	31	18	38	38	1.7	2010	3.1
Br.Sprout-NPK	30	13	2.4	10	7.4	0.3	973	4.3
Br.SproutYMFC	33	10	2.8	11	9.7	0.4	837	4.0
Pepper-NPK	153	30	6.0	21	11.5	0.7	61	2.6
Pepper-YMFC	182	27	5.2	21	17.6	0.6	123	2.6
Bean-NPK	179	33	5.0	8	8.8	0.4	48	1.9
Bean-YMFC	154	35	7.9	14	9.0	0.6	81	2.7
Tomato-NPK	180	37	7.6	10	17.8	0.6	431	2.6
Tomato-YMFC	192	37	8.2	13	20.3	0.7	290	3.4
Onion-NPK	119	16	1.4	2	2.5	0.2	191	1.7
Onion-YMFC	122	17	3.8	8	8.5	0.4	384	2.0
p-value	0.967	0.289	0.262	0.435	0.226	0.078	0.912	0.422

Table 7. Soil pH, CEC [cmol+]kg^{-1}, C and N (g kg^{-1}) and Mehlich-3 extractable nutrients (mg kg^{-1}) from the 1999 plots.

	pH	CEC	C	N	P	K	Ca	Mg	S	Fe
					Fertilizer Treatment					
Bean	6.09	11.3	27.0	2.27	65	83	1070	292	50	67
Broccoli	6.76	11.2	17.0	1.52	58	105	1350	384	49	76
Carrot	6.14	10.5	23.4	2.13	44	83	1240	333	52	87
Onion	6.92	11.7	16.3	1.28	62	65	1150	254	50	81
Pepper	6.75	10.4	28.2	2.28	43	75	1690	314	68	80
Tomato	6.52	10.1	16.7	1.37	54	92	1130	218	62	76
mean	6.53	10.9	21.4	1.81	54	84	1270	299	55	78
±s.d.	±0.35	±0.6	±5.5	±0.47	±9	±14	±230	±59	±8	±7
					Compost Treatment					
Bean	6.31	13.4	29.2	2.56	44	77	1460	343	56	75
Broccoli	6.66	11.6	23.4	1.83	52	100	1540	403	50	88
Carrot	7.01	11.4	27.5	2.34	41	78	1470	346	55	84
Onion	6.94	12.5	29.6	2.34	41	63	1270	237	66	83
Pepper	6.56	12.0	27.0	1.69	40	62	1730	320	56	84
Tomato	6.84	11.4	29.0	2.04	42	84	1320	263	83	68
mean	6.72	12.1	27.6	2.13	43	77	1470	318	61	80
±s.d.	±0.26	±0.8	±2.3	±0.34	±5	±14	±160	±60	±12	±7
p-value	0.280	0.005	0.045	0.025	0.005	0.010	0.010	0.118	0.281	0.423

	Mn	Cu	Zn	B	Cd	Cr	Na	Ni	Pb
					Fertilizer Treatment				
Bean	21	1.19	3.21	0.56	0.03	0.18	24.5	0.85	1.33
Broccoli	19	1.23	2.96	0.68	0.06	0.24	36.5	0.98	0.78
Carrot	25	0.90	4.93	0.51	0.07	0.19	20.5	0.75	0.53
Onion	24	1.36	3.52	0.56	0.05	0.25	23.1	0.99	0.82
Pepper	15	1.41	3.53	0.82	0.04	0.23	36.5	0.91	1.01
Tomato	15	1.37	3.84	0.72	0.07	0.34	38.5	0.82	0.75
mean	20	1.24	3.67	0.64	0.05	0.24	29.9	0.88	0.87
±s.d.	±4	±0.19	±0.69	±0.12	±0.02	±0.06	±8.1	±0.09	±0.27
					Compost Treatment				
Bean	28	1.49	4.50	0.99	0.10	0.32	25.9	0.81	1.69
Broccoli	23	1.39	2.93	0.89	0.07	0.19	21.2	0.73	0.87
Carrot	29	1.42	4.90	0.98	0.14	0.18	34.2	0.91	1.48
Onion	29	1.36	3.42	0.97	0.05	0.28	28.8	0.80	1.40
Pepper	19	1.25	3.05	0.78	0.05	0.15	25.2	0.80	1.09
Tomato	22	1.36	3.69	0.66	0.07	0.40	27.2	0.89	1.24
mean	25	1.38	3.75	0.88	0.08	0.25	27.1	0.82	1.30
±s.d.	±4	±0.08	±0.79	±0.13	±0.03	±0.10	±4.3	±0.07	±0.29
p-value	0.000	0.236	0.753	0.060	0.112	0.664	0.571	0.389	0.025

Table 8. Soil pH, CEC [cmol+]kg^{-1}, C and N (g kg^{-1}) and Mehlich-3 extractable nutrients (mg kg^{-1}) from the 2000 plots

	pH	CEC	C	N	P	K	Ca	Mg	S	Fe
					Fertilizer Treatment					
Bean	6.92	11.4	27.9	2.34	89	45	1560	131	83	209
Broccoli	6.09	11.1	22.9	1.75	124	65	1200	211	110	178
Carrot	6.75	10.7	23.1	2.24	131	161	1400	158	92	227
Onion	6.25	11.3	26.5	2.45	99	47	1260	192	81	181
Pepper	6.52	10.2	26.2	2.05	125	66	1120	214	96	116
Tomato	6.76	10.4	26.7	2.07	231	104	2140	252	107	183
mean	6.55	10.9	25.5	2.24	133	81	1450	193	95	182
±s.d.	±0.32	±0.49	±2.06	±0.25	±51	±44	±370	±43	±12	±38
					Compost Treatment					
Bean	6.94	13.9	29.1	2.41	95	41	1700	171	91	180
Broccoli	6.31	11.7	23.2	1.72	138	66	1970	243	85	248
Carrot	6.56	11.9	24.5	2.31	143	184	1620	176	97	173
Onion	6.34	12.8	27.4	2.37	105	52	1570	180	87	210
Pepper	6.84	12.4	25.8	2.17	132	63	1640	201	87	195
Tomato	6.66	11.7	27.0	2.11	208	95	2210	239	80	190
mean	6.61	12.4	26.2	2.18	137	84	1790	202	88	199
±s.d.	±0.26	±0.85	±2.12	±0.25	±40	±52	±250	±32	±6	±27
p-value	0.478	0.003	0.075	0.340	0.535	0.657	0.025	0.424	0.334	0.468

	Mn	Cu	Zn	B	Cd	Cr	Na	Ni	Pb
					Fertilizer Treatment				
Bean	19	1.48	2.08	0.68	0.01	0.20	100	0.91	0.52
Broccoli	30	1.18	3.95	0.76	0.03	0.22	188	0.81	0.91
Carrot	28	1.72	2.84	0.71	0.01	0.19	110	0.78	1.17
Onion	28	1.80	2.37	0.78	0.04	0.21	99	0.41	0.55
Pepper	22	1.83	2.71	0.86	0.03	0.25	114	0.57	0.27
Tomato	34	1.27	3.07	1.17	0.06	0.30	157	0.72	2.07
mean	27	1.55	2.84	0.83	0.03	0.23	128	0.70	0.92
±s.d.	±6	±0.28	±0.65	±0.18	±0.02	±0.04	±36	±0.18	±0.65
					Compost Treatment				
Bean	47	1.94	2.78	1.10	0.05	0.22	98	0.75	1.47
Broccoli	35	1.68	4.50	1.15	0.01	0.22	107	0.62	2.47
Carrot	41	2.67	3.00	1.18	0.05	0.20	122	0.71	3.15
Onion	35	1.87	3.17	0.98	0.02	0.19	102	0.56	1.15
Pepper	37	1.91	3.17	1.12	0.03	0.19	87	0.54	1.82
Tomato	43	2.01	3.15	1.35	0.04	0.19	88	0.44	2.27
mean	40	2.01	3.30	1.15	0.03	0.20	100	0.60	2.06
±s.d.	±5	±0.34	±0.61	±0.12	±0.02	±0.01	±13	±0.11	±0.73
p-value	0.012	0.023	0.011	0.001	0.793	0.246	0.149	0.175	0.009

In conclusion, mineralization of recently added and previously applied compost influence plant response in a particular crop year, especially for the high nutrient-demanding crops (brassica species). Seasonal variation in soil moisture and temperature seem to have a greater influence on plant production, through mineralization, than the source and amount of mature compost applied. In some years, compost is providing a higher level of available nutrients than the literature would predict, probably because the soil environment has more biological activity and is more conducive to mineralization from long-term organic applications

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FERTILISATION EFFECT OF THE P AND K SUPPLY WITH COMPOSTS

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In field tests for compost application over several years, which are carried out since 1995 in the Land of the Federal Republic Baden-Wuerttemberg on six typical field locations, also the fertilization efficiency of its P and K supply is tested.

	Phosphorus P_2O_5	Potassium K_2O
Supply with compost *absolutely* (kg/ha)	60 - 80	110 - 130
Efficiency of total fertilization *relatively* (% supply)	30 - 50	40 - 55
- Surplus crop uptake	4 - 8	3 - 6
- Increase of soluble pool in soil	25 - 40	35 - 50
Efficiency of min. fertilizer *relatively*		
- Year of application	15 - 20	50 - 60
- Duration of 10 – 20 years	40 - 50	100

Fig. 1. Efficiency of fertilization of P and K supply of compost – Application rate 6-10t DM ha $^{-1}$ y $^{-1}$

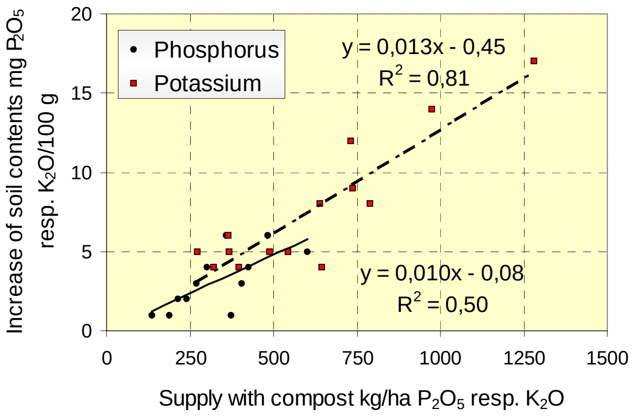

Fig. 2. Increase of soil contents (P, K) in relation to the supply (P, K) with compost

With a compost dosage of annually 6 - 10 t/ha dry matter an annually average freight for phosphorus of 60 - 80 kg/ha P_2O_5 as well as for potassium of 110 - 130 kg/ha K_2O is applied (see Fig. 1). The surplus uptake by the harvest products amounts to less than 10 % of the supply on the average. On the other hand the clear increase of the “plant available” soil contents is substantial. This fertilisation-effective pool in soil amounts to about 25-40 % with phosphorus and about 35-50 % with potassium of the supply by compost. Between the nutrient supply by composts and the “plant available” soil contents relatively good correlations exists (see Fig. 2). Thus the rate of increasing nutrient contents in soil per 100 kg of nutrient supply is about 1,0 mg P_2O_5/100g soil respectively 1,3 mg K_2O/100g soil. Commercial fertilizer normally do not have a fertilization efficiency of hundred per cent, too. For phosphorus fertilizers the fertilization efficiency is amounted to only 15 - 20 % in the application year, for potassium fertilizers 50 - 60 %.

Considering this the totally determined fertilization efficiency of the compost dosage of 30 - 50 % for the phosphorus supply and 40 - 60 % for the potassium supply is to be assessed as high. Therefore both nutrient supplies must be fully taken into account in the fertilization balance. That means that the phosphorus supply normally becomes the limiting factor of the compost dosage.

COMPOST APPLICATION TO ARABLE CROPS; EVIDENCE OF PLANT - NITROGEN DEPLETION?

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Compost was applied at two arable farm sites for two successive growing seasons. The initial rates of application on three replicated large scale field plots (minimum 20m x 25m) were zero, twenty and forty t ha-1 (DM) with farm standard fertiliser addition and three replicate plots of forty t ha-1 with no other fertilisation (compost only). In the second year the compost addition was increased by 50 %.

Farm A had a crop of potatoes (cv. Estima), followed by field beans (cv Socor), farm B had a crop of spring barley (cv. Optic) followed by spring oats (cv. Alder).

Results from the first year showed a decrease in potato yield of up to 29.3% ($p<0.05$) with no inorganic fertiliser and a reduction of 8.1% ($p>0.05$) with inorganic fertiliser. This has a corresponding reduction in the N content of the tubers of 28.5% where no inorganic fertiliser was applied. No differences between treatments were recorded for the yield of the spring barley. There was a reduction of 11% ($p>0.05$) in the grain N content of the barley where no inorganic fertiliser was applied.

Yield of beans was on average 6% lower on compost treated plots ($p>0.05$) and N content of the beans was increased on average by 5% ($p>0.05$). The yield of oats was reduced by 18% ($p>0.05$) where no inorganic fertiliser was added and a 10 % ($p>0.05$) reduction was recorded with inorganic fertiliser and compost. There was only a 2% reduction in the N content of the oat seeds (not significant) where no inorganic fertiliser was applied. Soil total nitrogen content showed no changes over the experimental period.

It is concluded that compost in terms of plant nutrient supply is not necessarily a replacement for inorganic nitrogen and may lead to yield decrease even when used with inorganic nitrogen. However the yield reductions recorded for spring oats and field beans were not statistically significant and therefore must be considered with great caution. The yield reduction and reduced N content of potato and spring barley may be due to the compost not being sufficiently mature at the time of application thus resulting in nitrogen immobilisation.

Introduction

Composted green waste is an integral part of the UK government recycling targets. The aim of a project carried out by the University of Liverpool, Waste Recycling Group and Cheshire County Council is to ascertain the sustainable use of composted green waste in arable crop production. Cheshire County Councils compost is made in an open windrow system using only domestic green waste material as feedstock. Arable crop production is currently considered to be the best market for composted greenwaste in Cheshire due to the economies of scale and volume of material, which could be absorbed. The project has successfully run for two years on two arable farms in Cheshire UK.

Materials and Methods

Compost was spread on the two farms with a Richard Western spreader. The fields were divided into a replicated randomised block design of twelve plots In the first year compost was applied at rates of 0, 20 and 40 t ha^{-1} dry matter with the farm standard inorganic fertiliser applications. In addition three plots of only compost at 40 t ha^{-1} dry matter with no additional inorganic fertiliser were also included.

In the second year of the experiment these rates were increased by 50% to give zero, 30 and 60 t ha-1 d.m. This was an attempt to stimulate a greater yield response from the compost by the addition of increased nutrient concentrations. Farm A in the first year had a crop of main crop potatoes (c.v. Estima) on a clay loam soil. This was followed in the second year by a crop of spring planted beans (c.v.Socor). Farm B on a sandy loam soil initially had a crop of spring barley (c.v Optic) followed by spring oats (c.v. Alder). Potatoes and beans were harvested by hand by taking sub samples from each plot. The crops were thus weighed and the tonnes per hectare calculated. For the cereals a trials combine harvester was used to give an accurate measure of the amount of crop harvested.

Results

Farm A

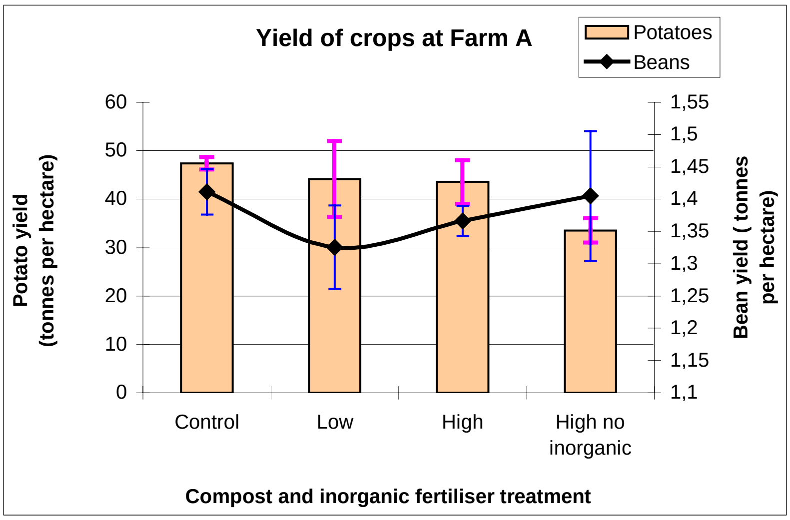

Fig. 1. Yield of crops in farm A

A significant decrease ($p<0.05$) in potato yield occurred at Farm A where no inorganic fertiliser was applied (Fig. 1) This equated to a loss in yield of 29.3 % or 13.9 t ha^{-1} compared to the control. This was especially apparent in the reduction in number and mass of larger sized tubers (> 65 mm) (data not shown). The compost treatments including inorganic fertiliser also caused a reduction in yield of 6.8% and 8.1%, 3.3. t ha^{-1} and 3.9 t ha^{-1} ($p>0.05$) for the low and high compost applications respectively.

Corresponding to these data are the N contents of the tubers (Fig. 3) which show a 28.5% reduction from the controls where no inorganic fertiliser was applied ($p<0.05$). A 15.4% reduction in total N concentration ($p>0.05$) occurred at the high rate of compost addition and farm standard inorganic fertiliser additions. In the second year of the experiment the yield of beans was 6% lower than the control plot for low rates of compost, and 3.2% lower than the control for high rates of compost with farm standard fertiliser and 0.5% lower than the control where no inorganic fertiliser was applied ($p>0.05$) (Fig. 1). N content of the beans increased by 5% ($p>0.05$) on the high rates of compost addition with and without inorganic fertiliser (Fig. 3). Due to the low nitrogen demand of beans no inorganic fertiliser was applied for that growing season and thus differences between plots were due to compost and residual fertiliser additions only.

Farm B

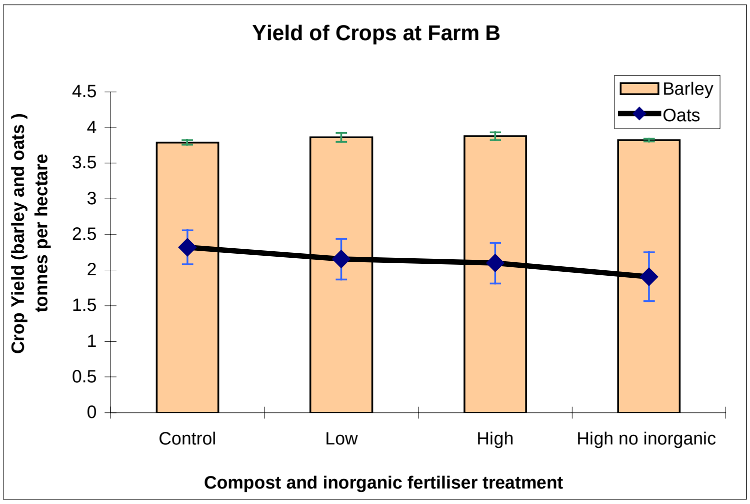

Fig. 2. Yield of crops in farm B

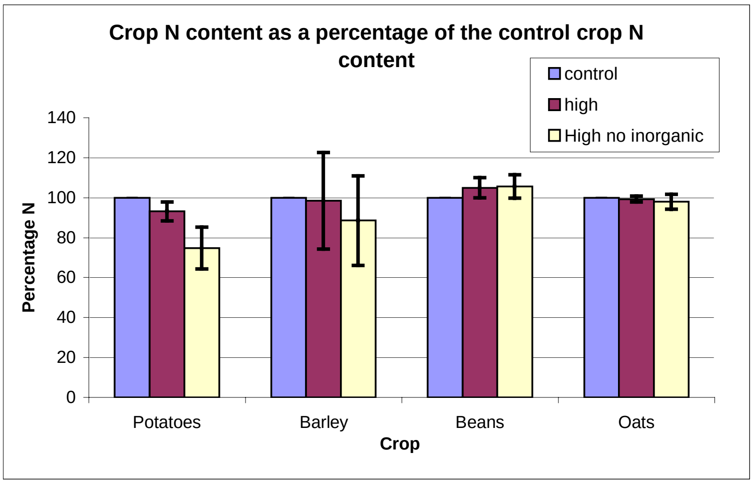

Fig. 3. Crop N content as the percentage of the control crop N content

There were no differences in barley yield in the first year (Fig. 2). However a 11% ($p>0.05$) reduction in grain N content occurred where no inorganic fertiliser was added. There was only a 1.5% difference in grain N content where high rates of compost and farm standard inorganic fertiliser was applied. In the second year the yield of oats (Fig. 2) fell by 18% where no inorganic fertiliser was applied and 7% and 10% respectively at the low and high rates of compost with farm standard inorganic fertiliser also ($p>0.05$). There was a slight reduction in total N content of the grain (2%) ($P>0.05$).

Discussion and Conclusions

Composted green waste is not sufficient as a source of nitrogen for high N demanding crops e.g. potatoes. The reduction in yield where compost was applied in addition to inorganic fertilisers indicates that nitrogen immobilisation also may have occurred. This is possibly due to the fact that the compost was not fully matured at the time of application. Therefore a nitrogen demand was exerted via soil microbial uptake. However these data are not statistically significant.

The yield data for the barley is encouraging as the plots where no inorganic fertiliser was applied showed no difference to the other plots. This however may have been due to the inherent fertility of the soil rather than a direct contribution of the compost.

The yield reductions for beans and oats were not statistically significant and therefore these results are inconclusive. It is surprising that there was a lack of correlation between the yield reduction of the oats and the reduction in oat grain nitrogen content. Therefore it is possible that the crop was not N limited. However other work by the authors (data not shown) demonstrates that other major nutrients (P, K, Mg or Ca) were deficient. It is possible that the reduced oat yield was due to climatic or disease pressure (the crop was heavily infested with cereal mildew) because the yield of the crop was poor (2.25 t ha^{-1}) when a yield in the region of 5.5 t ha^{-1} was anticipated.

The yield of beans was generally encouraging because the yield at the high rates of compost were roughly equal to those of the control plots. The reason for the depression in yield of the low rate of compost is possibly due to physical properties of the soil which suffered compaction during potato harvest. There was an increase in potassium concentration of the beans with increasing compost addition (data not shown). These data demonstrate that the use of compost is not a direct substitute for inorganic nitrogen. Also when used, compost should be fully mature to ensure that the soil nitrogen pool is not immobilised by the addition of composted material. After windrow composting, compost should be fully stabilised prior to application to arable land. The issue of compost quality is likely to be a key criterion in sustaining the use of compost in arable agriculture.

POTENTIAL USE AS FERTILISER OF A COMPOST FROM A MIXTURE OF RICE STRAW

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Abstract

Some urban organic residues such as sewage sludge from waste water treatment plants, and crop residues such as rice straw, produced in large amounts in our region, are potentially pollutants of the environment.

With the objective of converting these wastes in resources, we are studying in my institute the feasibility of transforming a substrate based on a mixture of sewage sludge and rice straw in a compost. For the experiment we used a substrate based on these two wastes, on the ratio 1:3 V/V and made four piles: 1)control, 2) application of urea, 3) application of an inoculant from mature compost, and 4) application of urea + inoculant.

In this contribution we indicate some relevant changes on the chemical and physico-chemical parameters occurred during the composting period.

As well as, based on the characteristics of the obtained compost, its potential use as organic fertiliser in agricultural soils is briefly discussed.

Session III

Compost impacts on soil biology and anti-phytopathogenic potential

INTRODUCTION

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Soil biology

Introduction

The soil is the home for an enormous number and variety of organisms. These organisms perform a wide range of functions which are a major contribution to what we consider to be a normal and healthy soil. It might be reasonably said that these organisms have an essential role in determining the functioning of the soil system.

The variety of organisms which exist within the soil is large ranging from large, visible organisms to organisms which can only be viewed under a powerful microscope. The larger soil animals are often referred to as the soil fauna, ranging in size from clearly visible earthworms and ants, to those that are visible only with some limited magnification. The micro-organisms are only visible using a higher magnification optical or electron microscope. Whilst small in size the numbers of micro-organisms in the soil are extremely large. The relative magnitudes by number and mass for a moderately fertile and, well drained soil are given in Table 1 for a selection of soil fauna and micro-organisms commonly found in soil.

Table 1. Numbers of organisms and approximate mass per m² of a fertile and well drained soil (several sources)

	Organism	Numbers	Mass(g)
Micro-organisms	Bacteria	$10^6 \times 10^6$	50
	Actinomycetes	$10^4 \times 10^6$	50
	Fungi	$10^3 \times 10^6$	100
	Algae	1×10^6	1
	Protozoa	1×10^6	<1
Soil Fauna	Earthworms	70	40
	Enchytraeid worms	1×10^4	2
	Gastropods	65	1
	Millipedes	75	2.5
	Centipedes	65	0.5
	Mites	1×10^5	1.0
	Springtails	5×10^4	0.6

It has been calculated that there may be of the order of 2.4 tonnes of soil organism per hectare in a fertile, well aerated soil

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. 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.

The response of soil micro-organisms to changing soil conditions

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 micro-organisms. For example Table 2 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 2. Populations of bacteria and fungi in soils and compost (EPA, 1998)

Material	Bacteria 10^6 per g (dry weight)	Fungi 10^3 per g (dry weight)
Fertile Soil	6-46	9-46
Soil recently reclaimed after surface mining	19-170	8-97
Pesticide contaminated mix of silt and clay	19	6
Mature Green waste Compost	417	155

Measures of soil microbial activity

Microbial activity in soil has long been used as an indicator of the quality or health of the soil and soil system. Indices of this microbial activity have been widely used in the assessment of the quality of the soil system. 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).

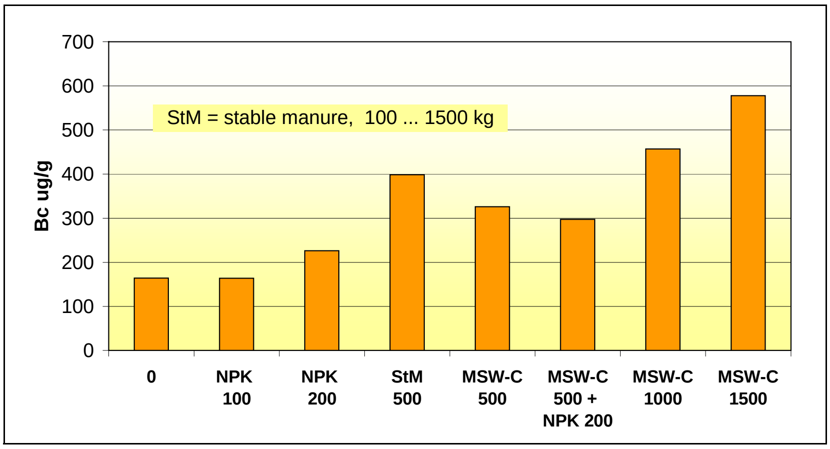


Fig. 1. Impact of mineral and organic amendments on Microbial Biomass (Leita et al., 1999)

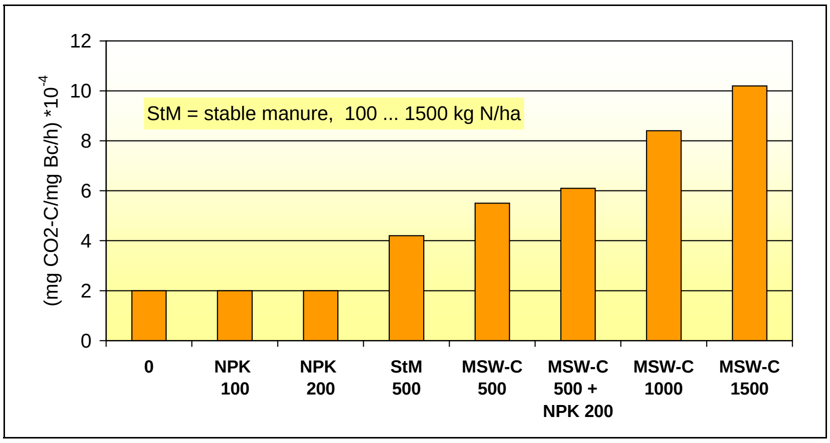


Fig. 2. Impact of mineral and organic amendments on Metabolic Quotient qCO2 (Leita et al., 1999)

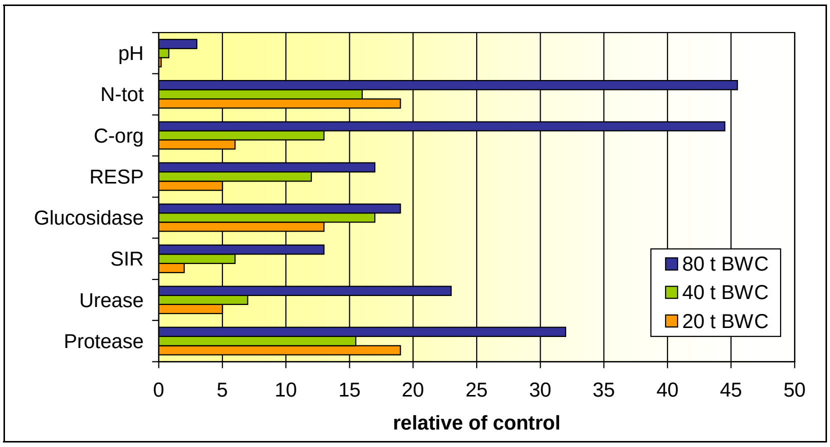


Fig. 3. Effect of Compost Application on Soil Quality Parameters (Schwaiger & Wieshofer, 1996)

Leita et al. (1999) used an index of 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 micro-organisms. The results shown in Fig. 1 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. 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}(Fig. 2).

Similarly Schwaiger and Wieshofer (1996) 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 t 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 t ha^{-1} treatment), with particularly marked changes for the enzyme activity and Total Nitrogen and Organic Carbon in the system (Fig. 3). 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.

Suppressive effects of composts against soil born plant diseases

The phenomena of suppression of soil born plant diseases as a result of compost application, has been reported since the early 60ies. (Bruns, 1998; Seidel, 1961; Reinmuth, 1963; Bochow, 1968a, 1968b; Bochow & Seidel, 1964). Systematic investigations. have been conducted since 1970ies. In the USA in that time a research for materials substituting the extensive use of peat has started. In the course of those investigations the scientists discovered the suppressive effect of bark and hard wood composts against soil born plant diseases (Hoitink, 1980).

Die range of mechanisms being responsible for the suppression phenomena are based on

- competition,
- antibiosis and
- hyper parasitism (Hoitink et al., 1996).

Suppressive Effects of composts depend of compost maturity. Only matured compost (best age: 3 – 6 months; Waldow et al., 2000) provides the desired antiphytopathogenic effect (Ferrara et al., 1996; Tuitert & Bollen, 1996; Waldow et al., 2000.). In contrary in fresh or not mature composts provide a milieu where the pathogens are supported in their development. However if stabilisation process has been conducted too far again the antagonistic effects declines again. (Hoitink et al., 1996). In addition an inoculation with bio-controlling substances must be carried out in practice. Other important factors are the time of compost application before planting, the salt content and the nutrient supply and availability. Table 3 gives some results for suppressive effects against *Phytium ultimum* and *Rhizochtonia solani* from the literature.

Table 3. Examples for the reduction of infection of by composts in % of *Phytium ultimum* and *Rhizochtonia solani*

Pathogen	Host	Compost	Reduction of infection %	source
P. ultimum	Several crops	BWC, GWC, CMC	Ca. 54 %, up to 80 in GWC at very high infection level	Bruns, 1998
Phytium ssp.	cress	21 BWC	up to 87 %	Erhart & Burian, 1997
P. ultimum, *R. solani*	Red beet beans	BWC, bark compost, CMC	25 – 40 %	Schüler et al., 1989
P. ultimum, *R. solani*	peas, beans, Red beet	BWC	39 % at initial compost donation 32 % at compost donation after 7 d	Schüler et al., 1989
P. ultimum	cucumber	GWC	up to 80 %	Waldow et al., 2000

BWC… biowaste compost ; GWC … green waste compost ; CMC … cattle manure compost

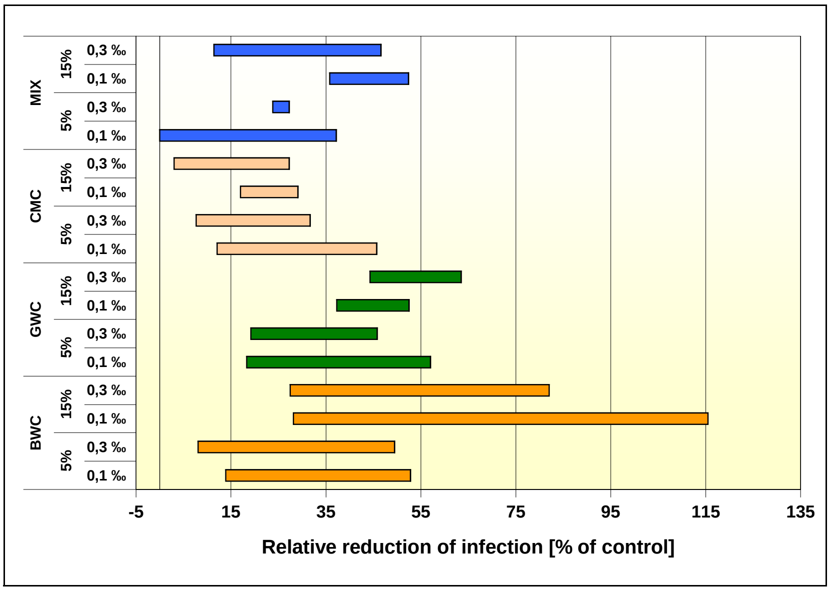
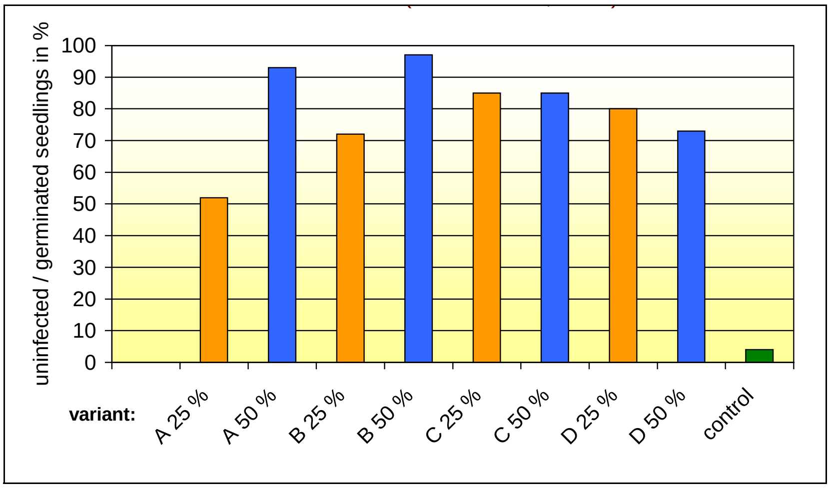


Fig. 4. Range of relative reduction of infection of *Pythium ultimum* at peas by four types of composts after 12 months rotting – parameter: fresh weight (legend see text; Bruns, 1998)



4 compost types: A… sewage sludge + poplar bark; B… industrial sludge + poplar bark; C… poplar bark; D… municipal solid waste compost
25 % and 50 %

Fig. 5. Suppressive Effect of Compost on *P. ultimum* on Cucumber (Ferrara et al., 1996)

Bruns (1998) investigated several compost types (compost made of biowaste (BWC), garden and park waste (GWC), cattle manure (CMC) and peat compost blend (MIX)) over a period of 4 years and found the most significant and constant effects for GWC and BWC. Fig. 4 demonstrates the range of the 4 results for the reduction of infection with *Pythium ultimum* at 2 infection levels (0,1 and 0,3 ‰) at peas.

Ferrara et al. (1996) found corresponding results when evaluating the proportion of uninfected seedlings of cucumber, basilicum, impatiens and beans. The Example of cucumber is shown in Fig. 5. The results also supported the hypothesis that mature composts are more effective with respect to antiphytopathogenic properties.

The following contributions give examples from long term trials demonstrating the importance of organic soil amendments for soil microbial community and as essential element in maintaining soil functions. Actual findings on the phenomena of suppressive effects against plant pathogens provide information on the possible interdependences of soil microbial activity and soil properties most likely being important for the mechanisms resulting in the suppressive effects against soil born plan pathogens.

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LONG-TERM EFFECTS OF MANURE COMPOST AND MINERAL FERTILISERS ON SOIL BIOLOGICAL ACTIVITY AS RELATED TO SOIL STRUCTURE AND CROP YIELD

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Introduction

In view of the growing human population, there is an urgent need for sustainable agricultural production. The intensification of production through the use of high-yielding varieties – with the associated high demand for fertilisers, pesticides and irrigation combined with intensive soil tillage – has led to a remarkable increase in crop yields, but also to serious environmental problems as regards soil fertility and biodiversity. This is alarming because biodiversity and soil fertility are essential to the sustainable functioning of the agricultural, forest, and natural ecosystems on which human life depends. As an alternative to these high input systems, farmers and researchers have developed organic farming systems which rely more on the use of recycled organic fertilisers such as manure and manure compost derived from the farm. There are two main organic farming systems: the bio-dynamic (BIODYN) and the bio-organic (BIOORG) production method. These systems as implemented in Europe are regulated in detail by the European Union (EU) Regulation (EEC) No. 2092/91. Both are usually referred to simply as 'organic farming'. The application of manure compost is a common practice on bio-dynamic farms, but also on specialised farms with high price crops such as vegetables. More fresh organic manure is applied on bio-organic farms. The question is, if the long-term application of manure compost can maintain soil fertility in the long-term and guarantee sustainable yields. Here we report the long-term agronomic and ecological performance of BIODYN and BIOORG systems in comparison with mineral fertilised conventional arable farming systems in Central Europe.

DOK Trial experimental set up

Table 1 shows the farming systems applied for 21 years in a seven year crop rotation, including cereals, root crops and grass-clover. The field experiment was set up in 1978 in the vicinity of Basle (at Therwil, Switzerland; 7° 33’ E, 47° 30’ N) by the Swiss Federal Research Station for Agroecology and Agriculture, Zurich-Reckenholz (CH), in cooperation with the Research Institute of Organic Agriculture, Frick (CH). Four farming systems were compared, differing mainly in their approaches to crop nutrition and plant protection (Mäder et al., 1999).

In the BIODYN and BIOORG farmyard manure (FYM) and slurry were applied corresponding to 1.4 LU/ha. One conventional system was fertilised with the same amount of FYM as the organic systems and, in addition, with mineral fertilisers up to the recommended level of the crop-specific Swiss standard recommendation (CONFYM system). The other conventional system received mineral fertilisers exclusively (CONMIN system). The conventional systems were farmed in accordance with the national guidelines for integrated plant production, a form of good agricultural practice. The soil is a haplic luvisol on alluvial loess. It contains 15% sand, 70% silt and 15% clay. Mean precipitation at the site is 785 mm per year and the annual mean temperature is 9.5 °C. The field trial was designed as a randomised block with four replicates, with three different crops planted each year. The individual plot size was 5 m by 20 m.

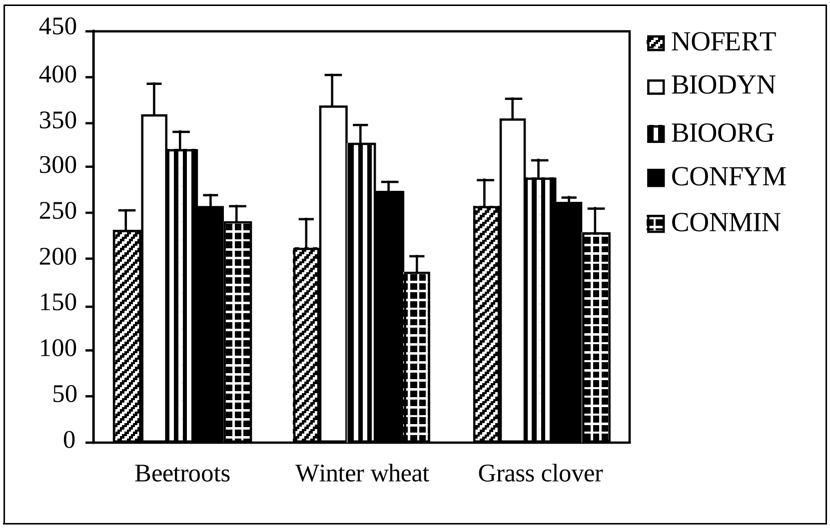
Table 1. Main differences between the farming systems of the DOK Trial

Treatments	**Organic systems**		**Conventional systems**	
	bio-dynamic **BIODYN**	**bio-organic** **BIOORG**	**with manure** **CONFYM**	**without manure (mineral NPK)** **CONMIN***
Fertilisation				
Farmyard manure (FYM)	composted FYM and slurry	rotted FYM and aerated slurry	stacked FYM and slurry	–
Livestock units per ha	1.4	1.4	1.4	–
Mineral fertilisers	–	rock dust, K Magnesia	NPK fertiliser as supplement	exclusively mineral NPK
Plant protection				
Weed control	mechanical	mechanical	mechanical and herbicides	mechanical and herbicides
Disease control	indirect methods	indirect methods, $CuSO_4$ on potatoes until 1991	chemical (thresholds)	chemical (thresholds)
Insect control	plant extracts, bio-control	plant extracts, bio-control	chemical (thresholds)	chemical (thresholds)
Special treatments	bio-dynamic preparations		plant growth regulators	plant growth regulators

* the CONMIN system was unfertilised in the 1st crop rotation

Enhanced microbial activity in compost manured field plots

Averaged over all crops, yield in both organic systems was 20 % lower than in the conventional systems, mainly as a result of the distinctly lower nutrient input, but also due to the different plant protection management. System effects on crop yield were most obvious with potatoes, caused by the high demand for nitrogen and potassium in a relatively short growing period. Winter wheat yields in the organic systems were about 10 % lower than in the conventional systems. Differences in grass-clover yield were small between the systems. Even though yield for all crops was lower in the biological systems, energy use per unit crop yield was 20 to 30 % lower than in the conventional system, except for potatoes. This was mainly due to the high need of energy used for the production of mineral synthetic fertilisers in the conventional systems. In general yield differences between BIODYN and BIOORG were small.



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.

Fig. 1. Soil microbial biomass (mg C_{mic}*kg soil^{-1}) under three crops after practising four farming systems for three crop rotations.

Soil phosphorus and potassium in a water extract did not differ in soils from BIODYN and CONMIN plots. 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 (Fig. 1). Moreover, the functional diversity of soil micro-organisms and their efficiency to metabolise organic carbon sources was increased in the organically fertilised systems with highest values in the compost manured BIODYN soils (Fließbach et al., 2000). We found a positive correlation between aggregate stability and microbial biomass ($r = 0.68$, $p < 0.05$), showing the importance of soil micro-organisms 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.

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EFFECT OF COMPOST APPLICATION ON THE SOIL MICROFLORA

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Introduction

Compost is used in agriculture as a fertiliser or to improve the physical structure of the soil. In addition, compost amended soil has been found to be suppressive against plant diseases caused by nematodes, bacteria, or soil-borne fungi in various cropping systems (Hoitink and Fahy, 1986; Ringer, 1998). However, the opposite, an increase of disease incidence due to a compost application, has also been demonstrated (Tuitert et al., 1998). Several reasons for these inconsistent results can be given. There are many types of compost, i.e. they differ in composition of organic materials and in maturity. In addition, the method and time of the compost application is important for the final effect in the field. Application of organic material just before planting the crop can even stimulate pathogens. Up to now, it is still difficult to predict the beneficial effect of compost products in plant pathosystems. To understand the influence of compost applications on soil suppressiveness, the microflora in soil before and after compost application has to be studied in more detail.

Compost is known to be a product rich in microbes, often containing 108 to 2 x 109 colony-forming units (CFU) of aerobic bacteria per gram dry matter (Postma et al., in press). However, the allowed application dosage of compost to agricultural soils is limited in the Netherlands (12 ton/ha per every second year, which is approx. 1 % w/w). Since agricultural soils themselves contain between 107 and 108 CFU aerobic bacteria per gram, the number of micro-organisms which are added through compost to a soil is not very impressive. However, the composition of the microflora in compost might be different, and the soil will be enriched with a variety of nutrients that will become available for the indigenous microflora.

Methods to characterise the microflora

To study the soil microflora, several methods are available which all give information about different aspects of that microflora. Thus, methods can yield quantitative versus qualitative data, can report on cultivable organisms versus total based on DNA (including dead organisms), or can describe specific functions present within the microflora. None of the available methods is able to give a complete explanation of the suppressive potential of the soil microflora. Therefore, a strategy of combining different types of methods is generally used.

A classical method is to compare the numbers of specific groups of cultural bacteria and fungi using plate counts on (semi)selective agar media. Many groups can be distinguished, such as fluorescent pseudomonads, filamentous actinomycetes, bacilli, etc. However, only the cultivable fractions of the soil population, which is often only 1-10 % of the total population, are thus analysed.

The microbial community structure and diversity can be analysed at the genetic level by PCR-DGGE community profiling (polymerase chain reaction - denaturing gradient gel electrophoresis).

This method allows the genetic fingerprinting of microbial populations in complex substrates with different levels of suppressiveness (Postma et al., 2000). PCR-DGGE profiles can be prepared with a focus on bacterial or fungal populations. Using nested PCR, also specific groups such as actinomycetes, pseudomonads, and bacilli can be analysed. With this technique, the non-cultivable fraction of the soil microflora is included in the profile. In addition, the possibility to identify bands in the profile following a cloning and sequencing procedure is very important, as this leads to a possible identification of the organisms present in the community.

The microbial population can also be analysed at a functional level with CLPP (community-level physiological profiling) using BIOLOG microtiter plates which contain 95 or 31 different single carbon sources. Microbial populations differ in their ability to use different carbon sources. By using BIOLOG microtiter plates the substrate utilisation pattern of the microbial community can be analysed (Garland and Mills, 1991; Waldrop et al., 2000). However, the results reflect the potential present in the microflora to utilise the different substrates, and not their in situ activity.

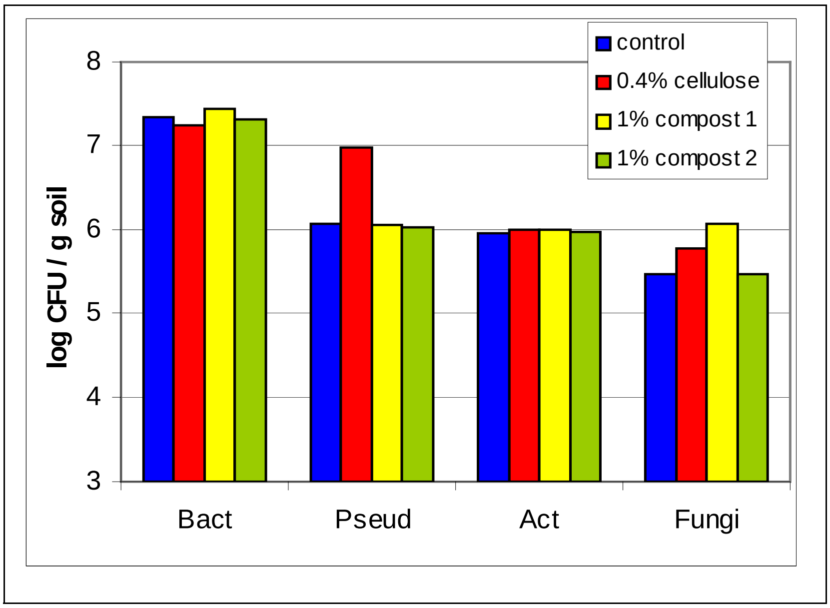
Furthermore, microbial activity can be analysed by different (fluorescent) staining techniques (TTC, FDA, CTC) or by measurement of soil respiration which gives information about the in situ activity.

A completely novel approach would be the use of DNA microarrays to report on the microbial status of complex substrates. Environmental DNA or RNA is hybridised to a microarray which contains a pre-selected range of DNA probes that are able to report on soil functional status. Problems to be solved with this highly innovative approach are a likely lack of sensitivity as well as cross-hybridisation.

Data on the soil microflora before and after compost application obtained with three of the above described methods will be discussed in the next paragraph.

Effect of different organic matter amendments on the soil microflora – a case study

Three types of organic matter, i.e. 0.4 % paper cellulose, 1 % spent mushroom compost and 1 % green-waste compost were mixed through a sandy soil, and incubated for 14 days at 18 °C. Then the microflora was characterised by 1) plate counts on semi-selective media, 2) ability to use the 31 carbon sources in Ecoplates (BIOLOG) and 3) genetic community profiling with PCR-DGGE. Results are shown in Figs. 1 to 3.

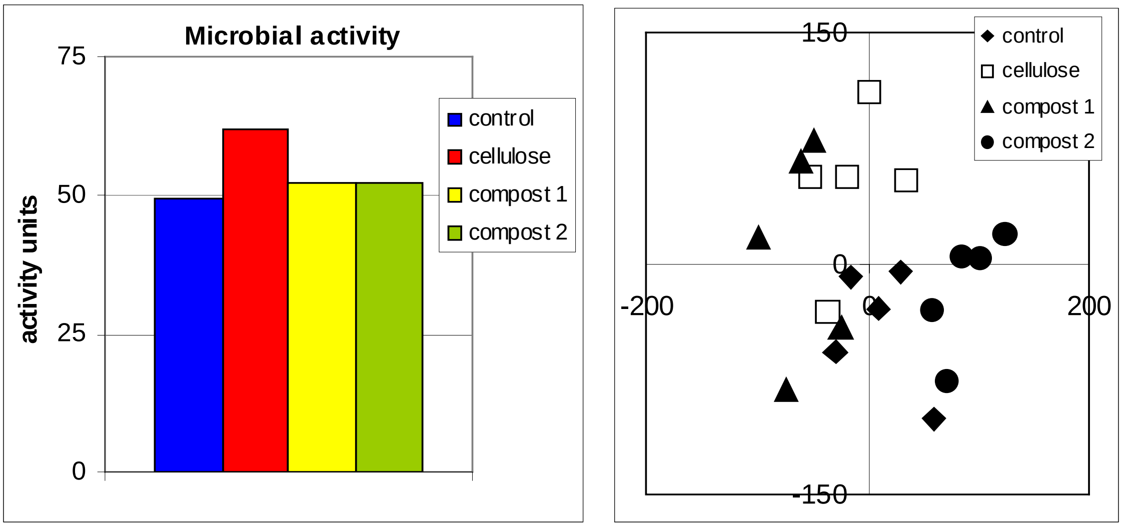


no amendment (control), 0.4 % paper cellulose (cellulose), 1 % spent mushroom compost (compost 1), or 1 % green-waste compost (compost 2). The enumerated micro-organisms are: total aerobic bacteria (Bact), fluorescent pseudomonads (Pseud), filamentous actinomycetes (Act), and fungi (Fungi). Least significant differences at P=0.05 are respectively: 0.16, 0.14, 0.19 and 0.12.

Fig. 1. Number of colony-forming units (CFU) of different groups of micro-organisms present in soil after amendment with different organic materials

Plate counts (Fig. 1) showed no differences for the total number of aerobic bacteria and filamentous actinomycetes, numbers of fluorescent pseudomonads increased only in the case that cellulose was amended, and numbers of fungi increased by amendment with cellulose as well as spent mushroom compost.

The potential microbial activity of the microflora in soil (Fig. 2A) was similar for most of the treatments, except for the cellulose amended treatment which had an increased potential activity.



no amendment (control), 0.4 % paper cellulose (cellulose), 1 % spent mushroom compost (compost 1), or 1 % green-waste compost (compost 2). A: Mean value of the reactions with 31 C-sources in the Eccoplates. B: Principal component analysis.

Fig. 2. Microbial activity measured in soil after amendment with different organic materials

However, principal component analysis of the BIOLOG data (Fig. 2B) showed a clear shift in the reaction of the microbial populations in soil after the different amendments. The cellulose and spent mushroom compost amended soil were different in their ability to use different carbon sources compared to the control and green-waste compost amended soil.

The genetic profiles of the bacterial populations in soil (Fig. 3) were distinctly different in all treatments. The control treatment had many week bands. In the treatments with the organic matter amendments few strong bands (depending on the type of organic matter) appeared. This means that some micro-organisms became more dominant, i.e. were stimulated by or introduced with the amendment, showing a decrease in species evenness.

Fig. 3. Genetic profile of the bacterial populations with PCR-DGGE in soil after amendment with different organic materials: no amendment (control), 0.4 % paper cellulose (cellulose), 1 % spent mushroom compost (compost 1), or 1 % green-waste compost (compost 2). The marker is composed of five known bacterial isolates.

Comparing the results of the different methods bring us to the following conclusions: the total number of cultivable micro-organisms did not increase by amendments, but the composition of the microflora was distinctly influenced in its genetic composition as well as in their ability to use different carbon sources (functional property). These microbial shifts occurred as a result of rather low concentrations of the amendments (i.e. 0.4 or 1 % w/w), and were dependent on the type of organic amendment.

In further studies, the type of organisms that are stimulated by the different types of organic amendment should be studied in relation to the effect on the crop.

Correlation between microflora and disease suppression

Different microbial characteristics have been analysed in relation with disease suppressiveness of different soil types or treatments (Alabouvette et al., 1985; Oyarzun, 1994; van Bruggen and Semenov, 2000; van Os and van Ginkel, 2001). Although microbial activity and biomass have been correlated with disease suppression (nutrient sink in suppressive soil), these community-level characteristics could not fully explain the level of disease suppressiveness. Van Os and van Ginkel (2001) showed that growth rate of a pathogenic Pythium species through differently treated soil, correlated negatively with dehydrogenase activity, microbial biomass as well as $^{14}CO_2$ respiration of the soil. However, a lower growth rate of the fungus through the soil was not always followed by a lower disease incidence level in the crop.

For disease suppression more properties of the microflora are suggested to be important: microbial diversity and the presence of specific suppressive micro-organisms or consortia might be necessary. Several studies showed a correlation between the presence of actinomycetes and disease suppression in soil or compost (Oyarzun, 1994 ; Workneh and van Bruggen, 1994; Craft and Nelson, 1996; Tuitert et al., 1998). Actinomycetes are key organisms in the decomposition of various organic substances and they are important producers of antibiotics, vitamins and many enzymes. Stimulation of actinomycetes after compost application as an explanation of increased soil suppressiveness is therefore an interesting hypothesis for further studies. Actinomycetes are only one example of a microbial group that might influence disease suppression. Other organisms responsible for disease suppression, in particular those of the non-cultivable fractions of soil micro-organisms, can be detected with molecular techniques such as PCR-DGGE.

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SUPPRESSIVE EFFECTS OF COMPOST ON SOIL BORNE PLANT DISEASES

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Suppressive effects of composts and other organic amendments is a phenomenon which has been known quite a time. Way back in the late 1950´s in the former GDR it was shown that compost use made it possible to reduce disease incidence of club root on crucifers to some extent (Bochow, 1958). A number of scientists from the US mainly worked with composted hardwood bark as an addition to container media for ornamentals. They showed very impressively the suppressive potential of hardwood bark composts towards soil borne pathogens (Hoitink et al., 1996, Hoitink and Boehm, 1999). In the meantime there are a number of publications describing the positive effects various composts have on the reduction of diseases caused by soil borne fungi. Among the materials evaluated were source separated bio-waste and yard waste composts (Schüler et al., 1989, Erhart and Burian, 1997, Tuitert et al., 1998, Bruns, 1998).

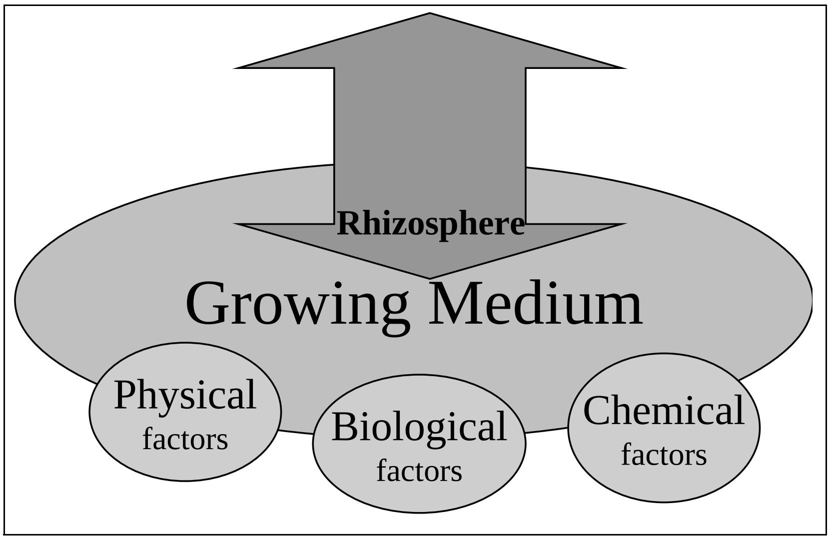

Fig. 1. Scheme of suppressive effects of composts affecting the rhizosphere.

Suppressive effects of composts on soil borne diseases can be defined as the result of the sum of physical, chemical and biological factors of compost use (Fig. 1). The rhizosphere as the main target of the pathogen's attack is affected by a number of features of the growing medium. Physical and chemical factors such as the proportion of water and air pores or the pH-value and the electrical conductivity as a result of nutrient contents have an increasing or decreasing impact on the pre-disposition of the plant. However, we know from the most publications that biological factors are governing the suppressive effects such as unspecific effects based on an increase of microbial activity or specific effects related to the diversity and composition of microbial populations (Hoitink and Boehm, 1999).

Introduction and objectives

The main objective of our studies is to find more details about the natural suppression of composts. Mainly this was done for source separated yard and bio waste compost but also for cattle manure composts. Nutrient contents of the materials ranged from low nutrient and salt content characterised by yard waste composts (YWC) (C/N ratio of 50 at the beginning and of 30 at the end the composting process) to materials with a high nutrient and salt content such as cattle manure composts (CMC) which started with a C/N ratio of 25 and were used with a C/N ratio of 10. Source separated biowaste composts (BWC) were between the both materials.

Until now bioassays are the most appropriate method to assess the complex of suppressive effects of composts. The general test set up contains a basic medium such as peat or sand (sterilised), one or two compost amendment levels and two infection levels plus the non-inoculated treatments. The control treatments are a 100 % basic medium with a mineral fertiliser to prevent nutrient deficiency.

The results of the bioassays showed that in comparison to the other tested composts originating from model composting systems, YWC was superior in reducing disease incidence caused by *P. ultimum* on peas (Table 1). On the average of the two infection levels with a disease severity of 64 (level 1) and 85 % (level 2) the amendment of 5 and 15 % YWC and BWC resulted in a significant reduction of the disease incidence up to 85 % compared to the control treatment. However, this was not the case with CMC.

Table 1. Suppressive effects of composts in the host pathogen system *P. ultimum – peas.* (Average of 18 bioassays)

	Reduction of Disease Incidence (%)[1)]	
	Biogenic Waste Compost/ Yard Waste Compost	Cattle Manure Compost
5% Compost amendment (v/v)	32	26
15% Compost amendment (v/v)	54	21

[1)] Reduction of Disease Incidence (%) RDI = $\frac{x - C(+)}{C(-) - C(+)}$ X equals the value of the tested treatment, C(+) equals the value of the inoculated, non amended control treatment and C(-) equals the value of the non-inoculated, non-amended control treatment.

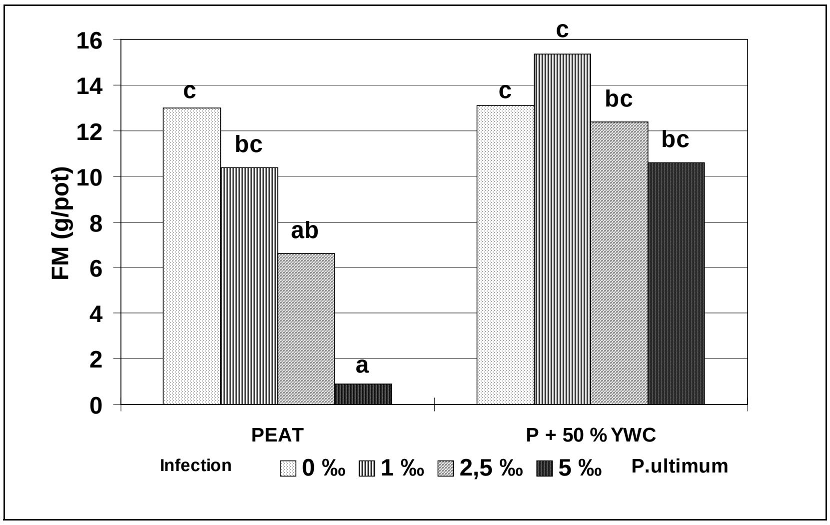

Fig. 2. The *P. ultimum* suppressive effects through compost addition (Yard Waste Compost (YWC) 50 % v/v) to a peat based growing medium observed with cucumber (n=5). Treatments with the same letters are not statistically different (LSD, p=0,05)

We could confirm these results in systems close to practical horticulture. YWC was the most suitable compost type to be used for horticultural purpose as it is low in nutrient and salt content and therefore tolerant to a wide range of plants. It can be used with a considerable volume in the potting mix and it is most sustainable with respect to suppression of soil borne diseases. Significant reduction of *Pythium spp.* root rot was observed with YWC when tested in compost amended commercial growing media. These bioassays were run in non sterilised basic media (Fig. 2). Similar results were obtained with other host-pathogen systems such as cucumber / *Rhizoctonia solani*, or tomato / *Phythophthora nicotianae* (Schüler et al., 1989, Bruns, 1998).

It was demonstrated in a current project that yard waste composts produced to a fixed schedule had suppressive properties during a period of one year. In a time series every three month the commercially produced composts from two composting plants were successful in suppressing *P. ultimum* in a standard bioassay with cucumber. Thus, the former results obtained with YWC from the model system could be confirmed. YWC from composting trial 1 reduced disease incidence up to 80 % in treatments with a strong disease severity of approx. 70 to 90 % (Table 2). So far, we could observe a slight trend that suppressive effects are dependent on the composting time. Material obtained in the age of 3 to 6 month seemed to be more effective than material from samples of the older composts. Although these results are preliminary, they demonstrate the possibility to produce suppressive composts on commercial composting plants using YWC. It was also shown in a system with poinsettia (*Euphorbia pulcherima*) - *P. ultimum* that the composts which controlled the disease in the standard systems can be successfully used in commercial potting mixes with a volume of 20 or 40 %. The reduction of disease incidence was up to 40 % although disease severity was up 80 % in the control treatments (Table 3).

Table 2. Suppressive effects of yard waste compost amended peat (50 % v/v) in the system cucumber – *Pythium ultimum*

Compost age (Month)		**3**	**4**	**6**	**9**
Disease severity [1]	Infection level 1	**∅ 53 %**			
	Infection level 2	**∅ 81 %**			
RDI [2]	Plant 1 Inf.-Level 1	n. d.	45	39	72
	Plant 1 Inf.-Level 2	80	72	28	39
	Plant 2 Inf.-Level 1	n. d.	85	87	26
	Plant 2 Inf.-Level 2	62	41	26	49

[1] Disease severity (%) = $\frac{CP(-) - CP(+)}{CP(-)} * 100$

Fresh matter of the infected peat control = $CP_{(+)}$
Fresh matter of the non-infected peat control = $CP_{(-)}$

[2] Reduction of Disease Incidence (%) RDI = $\frac{x - C(+)}{C(-) - C(+)}$

X equals the value of the tested treatment, *C(+)* equals the value of the inoculated, non amended control treatment and *C(-)* equals the value of the non-inoculated, non-amended control treatment.

Table 3. Suppressive effects of yard waste compost amended peat (50 % v/v) in the system *Euphorbia pulcherima – Pythium ultimum* (for 1) and 2) see Table 1)

Disease severity 1) Infection level 1	66 %
Disease severity Infection level 2	81 %

	20 % compost	40 % compost
Reduction of disease incidence 2) Inf.-Level 1	40	32
Reduction of disease incidence Inf.-Level 2	17	42

Conclusion

- 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.

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THE EFFECT OF VEGETABLE, FRUIT AND GARDEN WASTE (VFG) COMPOST ON THE BIOMASS PRODUCTION AND NUMBER OF EARTHWORMS IN A SILAGE MAIZE MONOCULTURE

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In 1997, we established our experiment on a sandy loam soil of the experimental site of Ghent University at Melle (Belgium, 50°59’ N, 03°49’ E, 11 m above sea level). The trial was established as a block design with three replicates. From 1997to 2001, we applied all possible combinations of the following three fertilization treatments on silage maize:

S: spring application of dairy cattle slurry of on average 42.3 Mg ha^{-1} (S+) or no slurry application (S-)

C: spring application of vegetable, fruit and garden waste (VGF) compost: 45Mg ha^{-1} every two years, starting in 1997 (C++), 22.5 Mg ha^{-1} every year (C+) or no compost (C-).

M: mineral N fertilization (Ammonium nitrate 27%) of 0, 100 or 200 kg N ha^{-1} year^{-1} (0N, 100N and 200N)

During the last week of July 2001, earthworms up to 25 cm of soil depth were caught, counted and weighed. The worms were driven out of the soil by changing electrical fields in a circle of 0.4 m in diameter (“Oktett-merhod”). Since earthworm densities are higher in than between maize rows, we placed the centre of the “catch circle” in a maize row. Earthworm populations are dynamic, so the experiment will be repeated following the winter 2001 – 2002 to draw more definite conclusions. The main results of the first observation (Table 1) were:

- Mineral N fertilization level had no significant effect on earthworm number or biomass
- Yearly slurry application had no significant effect on earthworm number or biomass
- Compost treatments showed a significantly higher amount of worms as well as a significantly higher earthworm biomass per ha.

Table 1. Biomass and number of earthworms in July 2001, following four years of organic treatment: 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

	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)

Acknowledgements: We thank Vlaco, the Flemish compost organization for financing the trial and the Louis Bolk Institute (The Netherlands) for the use of the “Oktett”- equipment.

FIRST RESULTS OF "MICROFARMING" IN LYSIANTHUS-TILLAGE ARE POSITIVE

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'Microfarming' offers a possibility for a healthy and environmentally safe tillage of Lysianthus (cut flower). This is one of the most important conclusions of an experimental research project carried out by second year's students at the University of Den Bosch. Reason for the research project is that there are difficulties with high loss numbers in the Lysianthus tillage caused by soil borne plant pathogens. The concept of Microfarming is that the soil life it self is capable of suppressing soil borne plant pathogens. Besides that, it supplies enough nutrients to the plant.

The most important disease causing pathogens are botrytis, myrothecium and pythium. Despite steaming, before every tillage round (every 14 weeks), and the use of chemical pesticides, loss percentages stays high. Many growers are meanwhile used to that, and are 'content' if the loss percentage stays at 15 %. A lower loss percentage would nevertheless be very desirable and Microfarming is capable of conducing to that.

Microfarming claims that a healthy soil is necessary for a healthy crop. A healthy soil has according to the Microfarming system a great microbiological diversity, the right biological balance (crop specific) and enough humus (by our opinion humus is something else then organic matter). These kinds of soils do have a great naturally disease-suppressing capacity and the potential to feed plants in the most optimal way. During tillage the naturally disease suppressing capacity of the plants and the soil is weekly stimulated (depending on disease pressure) by spraying biological active compost-tea. This tea is an extract and multiplication of the organisms from special Humus compost.

The research project was carried out in four sections, divided in Microfarming treatments (steamed and non-steamed) and conventional treatments (steamed and non-steamed).

The soil in the different sections was infected (inoculated with diseased plant materials) three weeks before planting. This was done to simulate the effect of year-round Lysianthus-tillage.

Three weeks later, two sections (one of both treatments) were steamed (90 ° C for 6 hours) just before planting. The other two sections were not steamed.

In the steamed Microfarming section a yield percentage of 99,3 % was achieved. The section with the steamed conventional system had loss numbers similar to common (in the Lysianthus tillage) results (a yield of 85,1 %).

Management:	Soil treatment:	Yield percentage:	Loss percentage:
Microfarming	Steaming	99.3	0.7
Conventional	Steaming	85.1	14.9
Microfarming	Non-steaming	77.2	22.8
Conventional	Non-steaming	71.9	28.1

In the conventional and Microfarming non-steamed sections the diseases were not controlled. The yield percentages in the non-steamed sections were low, because of an over-inoculation of high numbers of disease causing organisms at the beginning of the trial. Nor neither the conventional, nor the Microfarming systems were capable of suppressing diseases in the none-steamed sections.

Steaming did kill off all the present switcher nematodes. After one tillage-round new ones only appeared in the conventional sections!

In the steamed section of the micro-farming system these harmful nematodes did not appear after one tillage-round, actually in the non-steamed section of the Microfarming system the present root feeding nematodes disappeared during tillage (natural disease suppression) The density of these nematodes of about 30.000 root feeding nematodes per square meter was in this tillage section in hundred days reduced to 0 per square meter.

Conclusion, the Microfarming-system demands no chemical fertiliser or pesticides. It needs gas for steaming, only in case of a very sick soil, and than probably just once !

That’s why the costs of Microfarming, consisting of microbiological analyses, Humus compost and compost-tea are comparable with the costs of conventional systems.

Microfarming is a system that offers good possibilities to grow Lysianthus (cutting flowers) on a healthy, organic way. Condition is in most cases that the system starts on a steamed soil. From that moment on, the biological system can develop itself and is capable of suppressing diseases and supplying the right nutrients and the right amounts of nutrients to the plants. Probably the second Micro-farming tillage round can be started without steaming.

Session IV

Aspects of soil protection …. against potential pollutants

INTRODUCTION

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Compost – Consulting and Development, Austria

Soil – sink or source of potential pollutants?

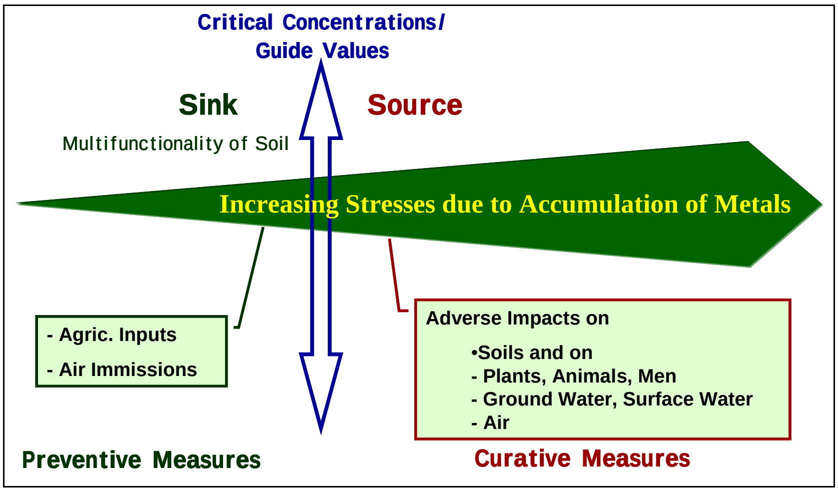


Fig. 1. Critical concentration decides whether the soil serves as sink or source of potential pollutants (Gupta, 1999)

Whether a potential pollutant compound or element may perform an adverse or impact on the environment depends on the concentration level in the relevant soil horizon. This critical concentration decides whether the soil serves as a sink or a source of a potential pollutant (see Fig. 1). This orientation value depends on soil and site specific properties such as pH, CEC (as a result of the sorption complex formed by clay and humus content and properties respectively) and cation distribution.

Thus, the threshold value for the multi-functionality of the soil is the critical point of any sustainable soil management. The accumulation scenario for Zinc shows that beside the quality and the amount of applied compost the critical concentration of the soil plays the important role for the assessment of the compost management option.

Scientifically based knowledge of the behaviour of the metals in the soil is the pre-condition for a reliable assessment of a sustainable compost management. The next step is the evaluation how soil concentration will change in time and what control mechanisms would be adequate in order to guarantee the functionality of the soil system. The Factors and assumptions to be considered are

- background concentration in soil
- average airborne deposition and export by leaching and plant uptake

- heavy metal concentration of composts under consideration of further mineralisation of the organic matter when applied to the soil (see below)
- time frame and yearly dosage of compost per ha and year (see below)
- maximum soil levels for heavy metals as orientation values for a certain management system (key parameter: the sustainable function of the soil)

The following heavy metal Zn concentrations in compost, related to 30% organic matter (O.M.) have been assumed:

- 2nd draft WD Class 1 (200 mg kg^{-1}) 10 t dm ha^{-1} y^{-1} and 30 t dm ha^{-1} y^{-1}
- 2nd draft WD Class 2 (400 mg kg^{-1}) 10 t dm ha^{-1} y^{-1}

Average airborne deposition and export of Zn (g ha^{-1}year^{-1}; see Amlinger, 1998):

airborne deposition	+912
export (leaching/uptake)	-334
balance	**+578**

It can easily be understood, that it is not the yearly load that we add to the *"heavy metal sink soil"* which gives the relevant figure in order to decide if the chosen management would be environmentally sound. It is the changing concentration level in relation to site and use specific requirements that concerns.

It is reasonable that we analyse a more or less *"total"* of the metal content in composts. The challenge is to know how a certain soil will incorporate the metals introduced within the compost matrix depending of the mentioned key properties like clay content, pH, SOM status and quality, CEC, porosity etc.. And this again may lead us to a certain more or less (still administrable ?) differentiated set of threshold values for soils with certain expected functions.

Fig. 2 gives an example for Zn and shows the potential accumulation after continuous compost application on the background of *precautionary limit values* as defined in the German Soil Protection Ordinance. The set of these precautionary thresholds for the multi-functionality of soils are based on risk assessment studies considering leaching and mobilisation behaviour as well as adverse effects on the biodiversity and soil microbia.

Table 1. Precautionary limit values for ZINC in the German Soil Protection Ordinance and in the Austrian standard

	Soil Protection Ordinance (Germany)			Austrian standard
	sand	silt/loam	clay	
mg kg^{-1} soil	60	150	200	300

It has to be considered that these figures are strongly linked to the specific climate and soil conditions in Germany and this gives a clear hint that the agreement of application regimes in relation to soil and site conditions has to be decided on a local level.

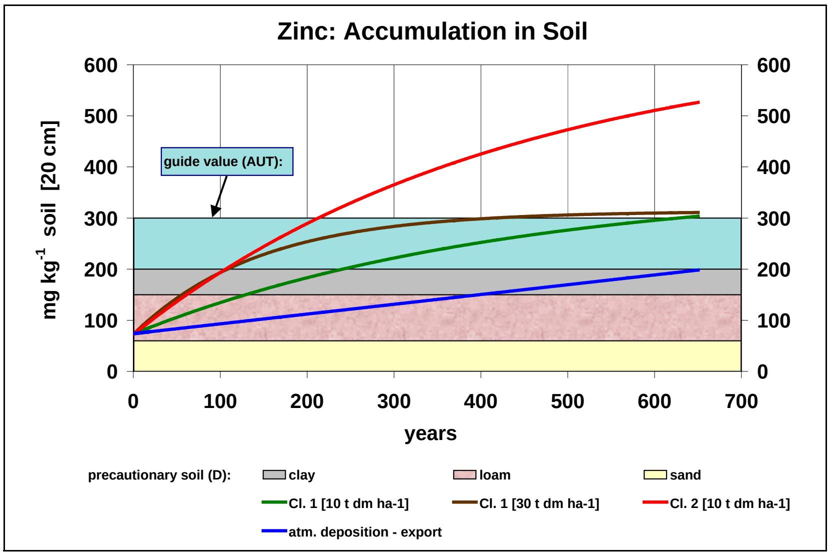
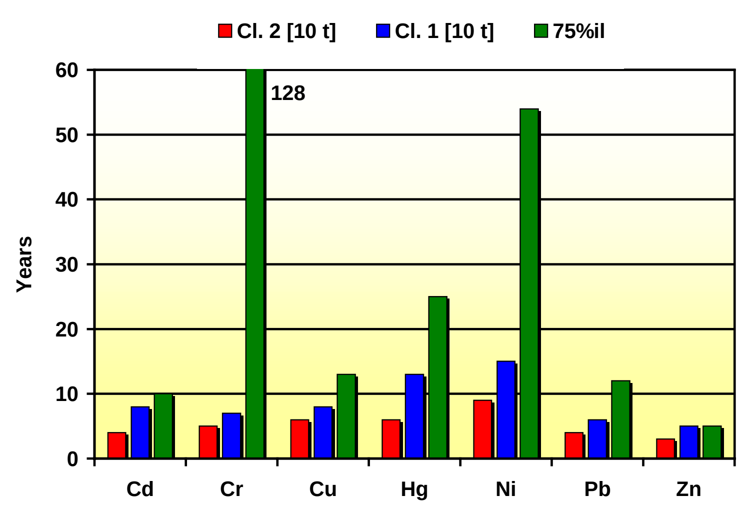


Fig. 2. Accumulation of heavy metals in the soil following continuous compost application in relation to precautionary limit values for agricultural soils (German Soil Protection Ordinance)



	mg kg^{-1} dm						
background soil	0.21	38	21	0,16	24	17	74
measurable increase	0.02	1.5	2.0	0.02	1.5	1.5	2.5
75%il BWC/AUT	0,51	31,0	60,8	0,29	25,7	49,0	210,5

Fig. 3. Period of time for measurable increase of heavy metal concentration in the soil

This gives a realistic picture about the accumulation scenario in the soil under the chosen scenarios. For example a compost application of class 2 at a yearly dosage of 10 t dm ha^{-1} would reach the German precautionary threshold level for clay soils within 100 years. In the case of class 1 this value is exceeded after a period of about 240 years.

If the critical guide value for a soil is decided to be 300 mg kg^{-1} Compost at 200 mg kg^{-1} Zn will hardly endanger multi-functionality, whereas at a compost level of 400 mg kg^{-1} it would take about 200 years until this mark would be reached. Finally we may decide if the development induced would be reasonable on the background of sustainable management principles for defined functions of the landscape.

Another question is: how long it will take that under a defined scenario we may detect any *"accumulation"* by means of analytical precision. In Fig. 3 the period until an analytical significant increase may be measured when compost of a certain quality is applied at rates of 10 t dm ha^{-1}y^{-1} (see also Kluge, contribution in this session). The heavy metal concentrations assumed are class 1 and class 2 of the 2nd draft of the working document and the 75-percentile of Austrian biowaste composts respectively.

Depending on the individual metal level of the used compost and the *distance* to background levels of the soil an increase in heavy metal contents in soil to an analytically measurable extent may be expected within a period of 3 (Zn; Cl. 2 WD-2nd draft) to 128 (Cr; 75th percentile of Austrian biowaste composts) years. Assuming realistic qualities for source separated biowaste and green compost with the exemption of Zn it will take more than 10 years until a change in soil would be measurable. The situation of course would change if the background concentration if the soil is increased.

In addition to these systematically considerations in our context it was to be asked what role SOM in general and compost application in specific would play for the sorption and release dynamics of potential toxic elements (PTEs) and for the behaviour (decay) of potential organic pollutants (POPs) would play.

Soil Organic Matter and Metals

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 sulfhydryl 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.

Metals Adsorption rates on 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. (see also the contribution of Petruzzelli & Pezzarossa and Leita et al. in this session).

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).

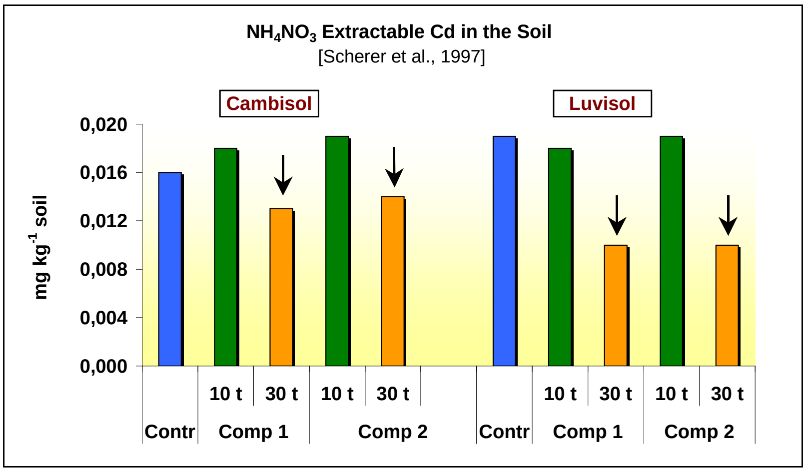


Fig. 4. Significant reduction of NH_4NO_3-soluble Cd at two compost amended sites

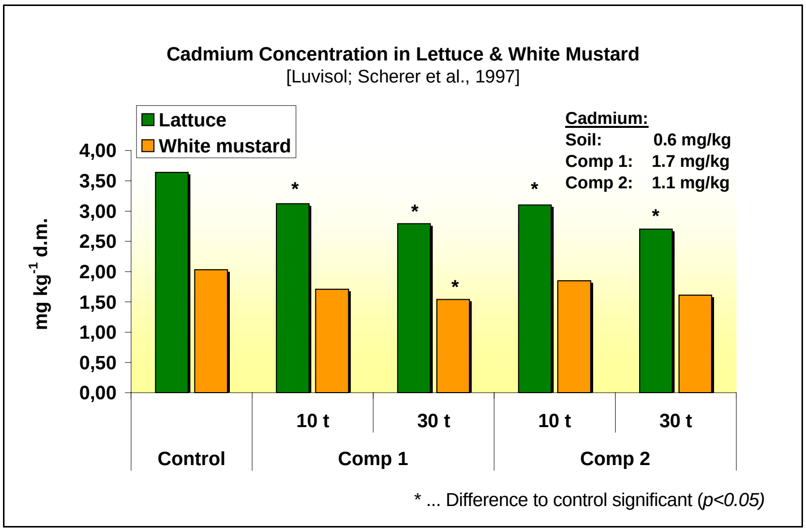
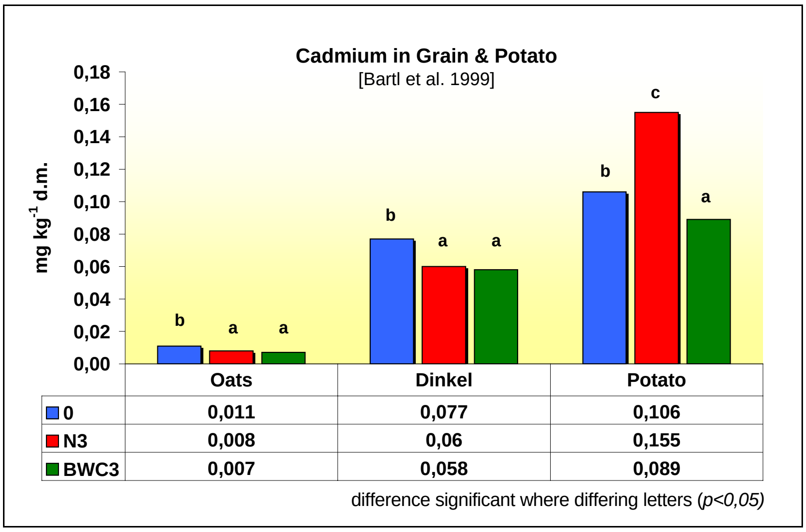


Fig 5. Cd concentration in two crops after compost application in a pot experiment (Luvisol; 2 types of compost; 10 and 30 t compost ha^{-1})



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

control (0 - fertilisation) a mineral fertilised system (N3) and a compost plot (BWC3; mean dosage: ca. 32 t ha^{-1} y^{-1} in 6 years)

Fig. 6. Cadmium in the grain of oats, dinkel and potatos

The example of Fig. 4 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 (Fig. 5). The result of another field experiment is shown in Fig. 6. After 6 years of continuous compost application (loamy silt; 6 repetitions; ca. 32 t 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*.

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.

Adsorption and Decomposition of Organic Contaminants

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 micro-organisms. The range of factors affecting the degradation of organic contaminants by micro-organisms 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.

With the exception of organo-chlorine insecticides composting tends to substantially decrease the concentrations of most pesticides that might be found in the source material.

The following examples may indicate the effect of compost amendments to support the degradation and the retainment (prevention of leaching) of pesticides in the soil respectively.

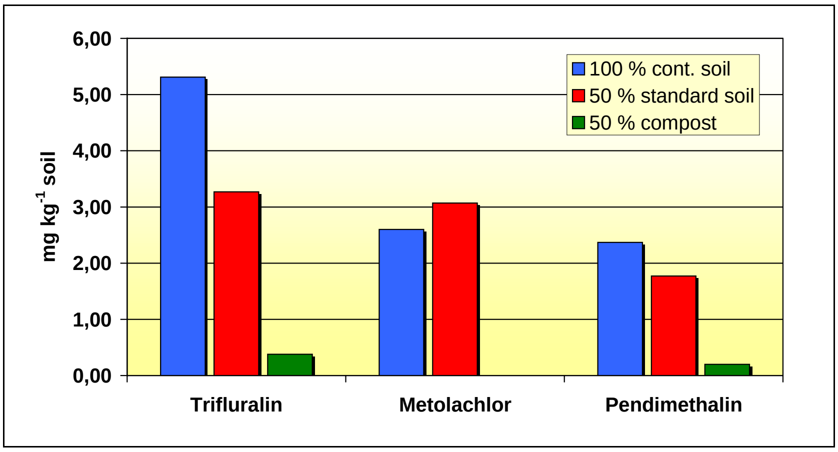


Fig. 7. Decay of pesticides in soil-compost blends (Cole et al., 1995)

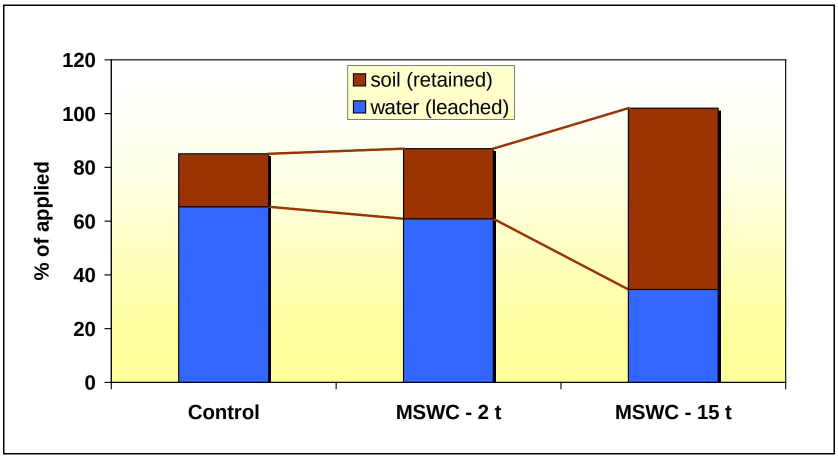


Fig. 8. Retainment and Leaching of Diazinon in a Soil amended with Compost (Sanches-Camanzano et al., 1997)

Due to the enhanced microbial activity Cole et al. (1995) found an increased degradation of 3 herbicides when a contaminated soil was incubated with 1 to 50 % compost and maize was grown within 40 days. Best results were achieved with 50 % compost addition (Fig. 7). Also Significant effects of compost additions on the decay of hydrocarbons in oil contaminated soils are reported (Hupe et al., 1996). Furthermore an increase of the sorption of hydrophobe pesticides is well correlated with maturity and amount of added compost (Diazinon and Linuron: Iglesias-Jimenez et al., 1997; Atrazin, Simazin, Terbutryn, Pendi–methalin, Dimefuron: Barri–uso et al., 1997). This phenomenon is declared by the colloidal properties of humic like substances which change the distribution and availability of hydrophobe/hydrophil surfaces of the soil matrix. The percolation experiment by Sanches-Camanzano et al. (1997) supports the findings of enhanced retainment in this case of diazinon in soils when amended with compost (Fig. 8).

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SORPTION AND AVAILABILITY DYNAMICS OF HEAVY METALS IN COMPOST AMENDED SYSTEMS

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Introduction

The European directives regarding wastes prioritise the various options for waste management. These are, in order of importance, reduction of waste production, recycling, energy recovery, and disposal. This hierarchy is based on the effects that each option has on the environment and sustainability is the guiding principle. The main aim of the 1999/31/CE directive on landfill is to guarantee a high level of environmental protection regarding waste disposal in the EU. Another important objective is to provide incentives for composting, biogasification and recycling. In a phase of ever growing waste production, typical of all the industrialised nations, it is clear that only one way of treatment can bring about ever more complex technical environmental and economic difficulties. As the problem is not only technical and scientific, but also political and economic, various areas of expertise and energy are involved, both scientific and social. In the European reality, landfill and incineration, among the possible options, meet strong opposition from general opinion, which increasingly calls for the recovery and recycling of wastes. In this context the quantity and the quality of the organic matter present in many municipal wastes, above all those coming from some selected uses, justify the choice of a biological treatment for the production of compost as a way of utilizing the waste. A correct composting process enables us to obtain material rich in humic organic matter, with properties similar to those of manure. This can be offered on the market of organic fertilisers, so reducing the amount of wastes to be landfilled or incinerated. The use in agriculture of good quality compost is an efficient means of re-establishing the balance between the withdrawal and restitution of organic matter in the biosphere. This is particularly important in Mediterranean soils, which are generally poor in organic matter (Legros and Petruzzelli, 2001). Other positive aspects, from both an agronomic and economic point of view, are the presence in the compost of essential elements for plant nutrition such as nitrogen, phosphorus, potassium and also an indirect agronomic effect. The positive effects of compost on plant growth are in fact due to an improvement in the structural characteristics of the soil, rather than to a direct input of immediately available mineral elements.

However, this practice can be notably limited by the presence in the compost of pollutants, in particular heavy metals. These can create environmental problems if the use of the compost is incorrect or not carefully monitored. In fact, whereas almost all the organic contaminants contained in wastes can be biodegraded by the biological processes in the soil, this does not occur for the heavy metals. They are not biodegradable and tend to persist and accumulate in the soil.

Heavy metals in compost treated soil

The content of heavy metals in compost is related to the materials utilized for its production. Some metals have a precise origin, whilst others are more uniformly distributed in all types of materials. Cadmium and zinc oxides and hydroxides, are present in high quantities in small batteries, whereas metal sulphides (CdS, ZnS) are commonly found in plastics. Lead and zinc oxides are very common in textile residues, whereas metal salts, such as sulphates and chlorides, can be found in various types of wastes. A suitable selection of the wastes coming from a correct source separated collection can therefore notably reduce the potential risks deriving from heavy metals. The total content of heavy metals in the compost is of primary importance, but also the chemical species in which a metal is present is of significant interest from the environmental point of view.

It is essential that the amount of these elements in the compost applied to agricultural soils does not reach the thresholds, which can affect either the soil fertility or the food chain.

Heavy metals can be present as salts (carbonates, sulphites, etc.), bound to organic matter, or in an adsorbed or exchangeable form. The predominance of a chemical species over the others depends on the origin and type of metal, and on the composting process (Leita and De Nobili 1991). Cationic species have a different mobility from that of complexed species being often the chelating agents humic-like substances with a considerable variety of molecular weights. The nature of the metal considerably influences the behaviour of these elements in the soil, above all immediately after the addition of compost.

To help the development of the composting process and in order to obtain a final product with good qualitative characteristics, it is important to obtain a suitable separation of the organic matter. Although we must take account of the important diversity of the chemical forms of heavy metals in compost, it is above all in the soil that we have the fundamental processes that move these elements into the food chain. The main factors that influence solubility, and therefore environmental mobility, are pH, cationic exchange capacity (C.E.C.), the organic matter and the water and thermal regime of the soil.

The activity of a metal ion in the soil solution depends directly or indirectly on the pH. Most of the ions able to precipitate the metals are weak acids, which become soluble following protonations and shifting of the metal in its solid phase. Besides, an increase in acidity reduces the number of specific adsorption sites available for heavy metals. The cationic exchange capacity regulates the mobility of metal ions. As this is a measurement of the negative charge on the constituents of the soil, the C.E.C. is an index of the soil's capacity to adsorb and hold metal cations. Both the organic matter and the clay minerals contribute to the C.E.C.: that deriving from the clays is generally little influenced by the pH, unlike the C.E.C. deriving from the organic matter.

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.

Sorption of heavy metals in soil

To establish whether heavy metals can damage the food chain, the most critical soil parameter is not their total content, but the amount of mobile species. This largely depends on the distribution of the metals between the liquid and the solid phases of the compost-soil system.

Transport and retention are the key processes affecting the fate and the behaviour of heavy metals in the soil. Transport of heavy metals in soils may occur through the soil solution by diffusion, by mass flow or by convection. Although transport through the gas phase of volatile compounds may be important under certain conditions, nearly all interactions between heavy metals and solid constituents of soil occur at the solid liquid interface. Most of the metals in the soil are transported in a dissolved or suspended form and absorbed by plant roots.

Through the retention, the soil surfaces hold heavy metals and affect their transport to the ground water, the surface waters and the atmosphere. Retention of heavy metals, which is mainly related to the adsorption process, but also includes absorption by the soil matrix and by soil organisms, is controlled by processes that are similar to those governing the behaviour of other cations. Even though the metals often occur in very low concentration in soil, they are able to compete for adsorbing surfaces with the much more abundant cations of alkali and alkaline earth metals. Thus, selective ‘specific’ adsorption reaction mechanisms are needed to explain their behaviour.

Adsorption is defined as the accumulation of heavy metals at either the soil-water or the soil-air interface. It refers to a reversible process involving the attraction of a metal ion to the soil surfaces and its retention for a time that depends on the affinity of the metal for the surface. The retention process includes chemical adsorption, physical sorption and precipitation. The sorption processes are highly complex due to the soil heterogeneity and to the soil's contiguity with biological, atmospheric, and water systems. Therefore, one of the keys to understand the mechanisms of the retention process is the composition of the soil matrix.

Soil consists of three phases: a solid phase, comprised of both organic and inorganic solids, a liquid phase, and a gas phase. The last two are the primary ways by which soluble and volatile heavy metals are transported, while the solid phase is the primary site for heavy metal accumulation. The major components of the solid phase significant for adsorption are: clay minerals, organic matter, oxides and hydrated metal (Al, Fe, Mn) oxides. Each of these components contributes to soil adsorptive properties both through their own adsorptive surfaces and through interactions with the others.

In compost treated soils the role of organic matter is of paramount importance. Natural humic materials accumulate on surfaces of natural soils as a result of the decay of plant and animal life. The importance of the organic matter to soil sorption is well documented for many heavy metals (Schnitzer, 2000). Even though the exact structure of humic substances is still largely unknown, they contain different organic functional groups able to interact with heavy metals. They include carboxyl, carbonyl, phenyl hydroxyl, amino, imidazole, sulfhydryl, and sulfonic groups, whose interactions lead to a wide range of reactive surfaces for heavy metals

The high degree of selectivity of organic matter indicates how heavy metals form inner sphere complexes with the functional groups rather than be adsorbed by means of simple exchange reactions. The selectivity of humic matter depends on the degree of loading, that is on the amount of metals compared with the number of adsorption sites (McBride, 1989).

ESR spectroscopic analyses show, furthermore, the formation of covalent bonds with heavy metals, especially when they are present at low concentrations, following interactions with amino-type N groups. On the contrary, in the presence of very high amounts of metals, bonds with a limited covalent character, where the metal interacts with O-containing groups, are formed. In general, the strongest bonds are formed with metals, which have a great electronegativity (McBride, 1989).

The interest in the study of the adsorption of heavy metals has emerged particularly in cases in which waste products, such as sludges or compost, are added to soil. This practice in fact not only introduces relevant quantities of heavy metals into the soil, but also organic materials, which can naturally influence the dynamics of the metals in the soil.

Few models have been proposed to describe the retention/release reactions of metals in soils. These are based on adsorption equations which theoretically refer to a state of equilibrium in which the rate of adsorption and desorption are equal. This implies a consideration of the reversible process, but some metal species are irreversibly held by the solid phase due to the formation of bonds, which are not exclusively electrostatic. Despite these theoretical limitations, several models both empirical and mechanistic are commonly used. All the models are mathematically expressed for a quantitative description of the phenomenon.

The mechanistic models are based on thermodynamic concepts, which include the law of action of mass, chemical equilibrium, the principle of mass balance and electroneutrality. An empirical model, on the other hand, can be constructed using exclusively mathematical parameters, without taking account of any chemical-physical law. Moreover, certain parts of the mechanistic models can be considered empirical, when some chemical-physical correlations are arbitrarily assumed. Mechanistic models for describing heavy metal sorption are often preferred to the empirical ones since they agree better with experimental data. They in fact take into account the change of surface charges accompanying heavy metal sorption by soil. While these models by themselves cannot provide any information about the mechanism of metal retention/release reactions in soils, they can be used to describe and predict the reactions, suggesting the mechanisms that could be defined by further study.

Langmuir's equation is probably the most widely used. Although it was originally derived for the study of the adsorption of gases, it has been used successfully in many soils in relation to the heavy metal adsorption.

This equation is based on the following assumptions:

a) the energy of adsorption is constant and independent of the degree of surface coverage

b) adsorption occurs at simple localised sites without phenomena of interaction between the molecules of adsorbate

c) the maximum adsorption possible is that of a monomolecular layer.

The most common forms of the Langmuir equation are:

$$q = \frac{q_{max}K[M]}{1+K[M]} \qquad \text{or} \qquad x/m = q = \frac{bKC}{1+KC}$$

Where q or x/m are the amount of metal sorbed per unity of mass of soil, C is the equilibrium concentration, b (qmax), and K are adjustable parameters linked to the maximum and energy of adsorption.

The Langmuir approach to the adsorption phenomena is based on the assumption that the bonding energy of all the adsorbing sites is uniform. This is often not true in soils where more than one type of reacting surface exists. However, whenever the adsorption reactions approach saturation with increasing concentration, it has been recognised that the conditions allow to approximate the description of sorption with a Langmuir equation.

Despite the theoretical limitations and those derived from the impossibility to distinguish between sorption and precipitation reactions, the equation cannot be considered as exclusively empirical.

The values of b and K in fact can be independently determined, for example by kinetics and crystallography (Schulthness and Sparks, 1991). This equation is of particular interest in assessing the pollution of a soil, because it is possible to quantify a maximum adsorbing capacity, as regards heavy metals, allowing a comparison among soils treated with compost.

Field experiments have shown that in the long term the levels of mobile metals added to soil stabilise at lower values, and bioavailability is reduced (Ford et al., 2001). This phenomenon can be ascribed also to the protective action of the organic matter added, which can greatly contribute to irreversible retention due to the high energy bonding among heavy metals and organic matter.

A lively debate exists on the possibility that this protection can be considered permanent or effective for all toxic metals, even in the long term. To contribute to this scientific debate, experiments were carried out to evaluate the sorption properties of a soil, which has been treated for 5 years with high rate of composted sewage sludge. Then the soil remained untreated for 15 years and it was possible to evaluate the residual effect of compost addition on the soil sorption capacity (Petruzzelli et al., 1997).

Heavy metal sorption was significantly different in the treated and in the untreated soil, showing that even after 15 years the addition of compost markedly affected the sorption.

In the untreated and in the compost treated soil the isotherms of cadmium and zinc could be classified as ‘L type’ (Giles et al.1960). However compost treated soil was characterized by an increase in the sorption capacity, showing a greater affinity between the metal ions and the adsorbing surfaces (Fig. 1 and 2). A possible explanation for these findings is that new adsorbing sites become available on the solid phase of the soil following compost addition (Petruzzelli et al. 1992, 1994), and that these sites were still active 15 years after the cessation of compost addition to soil. The results obtained in this field experiment confirm previous findings of laboratory sorption trials carried out on the same soil. A detailed analytical characterization (NMR, IR and HPLC) showed that the soil was able to retain different organic compounds after mixing with a sludge extract (Petronio et al., 1994; Petruzzelli et al., 1997).

The degree of changes that might occur in the soil properties seem to be related to the properties of the compost added. Compounds of organic nature, contained in the compost, adsorb on the soil and provide new adsorbing sites for the heavy metals. The metal bonding by the organic functional groups might not be only an ion exchange, but the high degree of selectivity shown in the sorption suggests that metals coordinate directly.

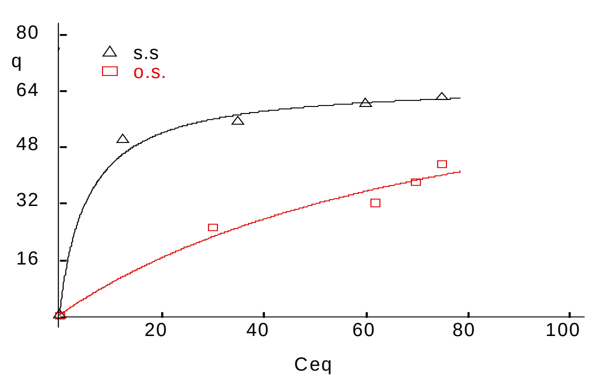

Fig. 1. Sorption isotherms of zinc in original (o.s.) and sludge treated (s.s.) soil

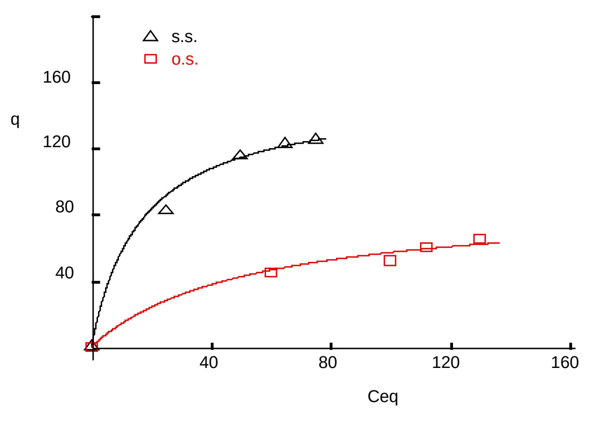

Fig. 2. Sorption isotherms of cadmium in original (o.s.) and sludge treated (s.s.) soil

The shape of the sorption isotherms was not linear, and they all could be described adequately by the Langmuir equation.

Based on the values of the parameter qm, the adsorption capacity for the investigated metals increased in soil treated with composted sludge. The degree of the amount sorbed increased of more than 75% for zinc and more than 27% for cadmium.

The adsorption process may be interpreted also by the use of the distribution coefficient Kd, defined as the ratio of the amount of metal sorbed by soil vs the equilibrium solution concentration of the metal:

$$\mathrm{Kd} = \frac{q}{C}$$

The distribution curves (Kd values vs equilibrium concentrations) for Zn and Cd are shown in Fig. 3 and 4.

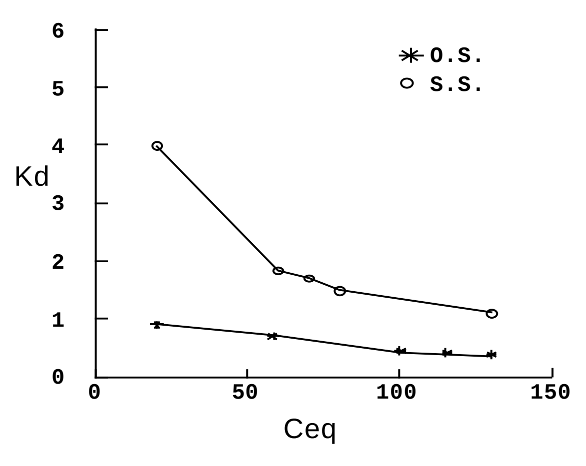

Fig. 3. Relationship between Kd of zinc and equilibrium Zn concentration

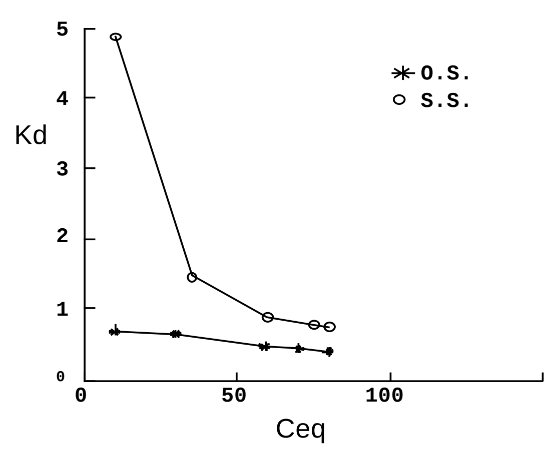

Fig. 4. Relationship between Kd of cadmium and equilibrium Cd concentration

It is apparent that the values of the distribution coefficients Kd were always higher in soil treated with composted sludge for both metals. In the treated soil Kd values were particularly high at low concentrations of the metal in the equilibrium solution, whereas the values were lower at high concentration of the metal in solution.

The decrease of Kd values at high concentration of metal in the equilibrium solution were due to the relatively lower adsorption by the soil, which in turn is related to the sites available on the soil surfaces or compost surfaces. It is likely that the adsorbing sites derived from compost were saturated and the adsorptive capacity of the treated soil became similar to that of the control soil. The Kd curves, in fact, tend to become coincident at the highest value of concentration of metals at equilibrium.

It is important to stress that since the soil sorption capacity is inversely related to the amount of metal sorbed, the low-metal biomasses are more suitable to provide new sorbing sites. In any case adsorbing capacities decrease with the increase in the ‘covering’ of the adsorbing surfaces by the heavy metals. These findings support the hypothesis that the sorptive properties of biomasses can prevent the release of heavy metals and their excessive uptake by crops.

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). In the above cited experiment the amount of organic matter in treated soils was unchanged from the end of compost addition and was still higher than in control plot.

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 biowastes, which does not decrease with time, and can positively contribute to reduce phytoavailability of trace metals.

The data obtained are according to previous long term experiments (Davis and Carlton-Smith, 1984) which showed a fairly constant extractability following the cessation of biomass application. They also showed a slow change in the bioavailability of heavy metals; with about 30% of organic matter derived from biomasses remained in the soil. The residual organic matter can therefore play an essential role in retaining heavy metals and in increasing soil sorptive properties. These metals in turn can protect organic matter by exerting a toxic effect against the microorganisms, which are able to decompose humic-like materials.

It has been recognised that metal sorption on soil surfaces is not completely reversible and sorbed metals are not generally labile (Kretzschmar and Voegelin, 2001). This is confirmed by the fact that patterns of metal desorption generally differ markedly from those of metal sorption. Differences in sorption and desorption should moreover indicate the complexity of sorption mechanisms, which are often slow and changing in rate over time, not achieving a true equilibrium conditions.

In soils treated with weakly contaminated compost, the release and bioavailability of metals is strongly controlled by compost chemistry which can contribute to remove ions from soil solution by ion exchange and specific sorption or chemisorption.

The energy of the sorption processes is the results of both long-range electrostatic forces and short-range covalent bonding.

Ion exchange is a reversible process characterized by electrostatic attractive forces. The metal cations are retained by a non-specific electrostatic attraction, the adsorption of a metal ion resulting in the simultaneous release of equivalent amounts of other cationic species. When a metal ion is sorbed by other forces besides the electrostatic, specific sorption occurs and covalent bonding dominates.

Specific sorption involves a sharing of electrons between the heavy metal and the surface, since a chemical bond is formed between the adsorbed metal and the underlying surface. Chemisorption, being a chemical process, requires activation energy and so proceeds at a limited rate, which increases rapidly with a rise of the temperature. It has also been found that a slower retention process follows a rapid chemisorption.

Ion adsorption processes are influenced by different soil conditions such as pH, C.E.C., ionic strength, surface area, temperature, and the presence of competing cations and of organic and inorganic ligands. Addition of compost increases the buffering capacity of the soil, enhancing its adsorptive properties of soil, since reductions in metal sorption occur as pH and cation exchange capacity are reduced.

Absorption of heavy metals by plants

In using biomass in agriculture the main worries derive from potential pollution of the soil by heavy metals. This means above all deterioration in water quality and the entry of these elements into the food chain. The most important question is therefore to determine if use of the compost can provoke an increase in heavy metal concentration that is in their mobility and bioavailability, with consequent effects of phytotoxicity or contamination of the food chain.

The capacity of plants to accumulate metals, like that of the soil, is limited. For some metals, like Zn and Cd, most plant species show an increase in concentration proportional to the total content of the soil. For others, such as Pb and Cu, the content in the plants is relatively independent of the amounts present in the soil.

The movement of metals in the soil solution in the form of free or coordinated ions can occur in two ways. The first one is through convection or mass flow, during the process of absorption by the plant of the water that will then be transpired. The second one is by means of diffusion, following the concentration gradient that is created between roots and soil. The 'chelating' substances with low molecular weight have a great importance both in movement by convection and by diffusion, as they are able to chelate the metals, including them in their molecule. These substances, which are typical of well-developed humic compost, reduce the activity of the metals in an ionic form in the soil solution and their absorption by the plant, forcing the root to compete with the chelating substances or let the chelated metal enter. At the same time, however, if added to the soil, they can increase the amount of metals available and promote the movements through convection and diffusion of the metals.

The metals can be absorbed actively or by means of passive diffusion or they can be accumulated through active absorption with which the cations of macronutrients are absorbed. There is competition between metals both regarding chelation, and therefore movement towards roots, and also regarding absorption by the roots themselves. Further interactions exist between metals and nutrients and between metals and soluble salts. An example is selenium, an element with chemical and physical properties intermediate between those of a metal and non-metal. It has great environmental importance because of its increasing man-produced contribution, which has influenced the natural biogeochemical cycles. The accumulation of selenium in plants is influenced, among others, by the presence of the PO_4^{2-} and SO_4^{2-} ions (Pezzarossa et al., 1999).

The capacity of plants to accumulate metals is influenced, apart from the physical and chemical soil properties that cause the phyto-availability of the metals themselves, also by other factors such as species, cultivar and plant age.

The various species differ both in terms of accumulating capacity, and in their sensitivity and tolerance to the effects of the metals. The various species differ both in terms of accumulating capacity, and in their sensitivity and tolerance to the effects of the metals. Brassica oleracea botrytis (cauliflower), Brassica rapa (turnip) and Beta vulgaris (beetroot) are considered to be very sensitive, whereas Zea mays (maize), Glicine max (soya) and pasture are more tolerant. The metals are not evenly distributed in the various parts of the plant, but there are differences depending on species and metal. In Lycopersicon esculentum (tomato) higher concentrations of Cd have been found in the root system (Pezzarossa et al., 1991), but in other species concentrations of this metal are more commonly found in the epigeal parts. Cu tends to remain in the roots and Pb, Cr and Hg rarely accumulate in the epigeal parts. Zn is found at higher concentrations in seedlings and decreases with the age of the plant. In general the seeds (or the caryopses) have concentrations of most metals that are lower that those in the vegetative tissues. In soya, for example, metal content is much higher in the leaves than in the pods. Even more notable is the difference for maize, where Cd and Zn concentrations in plants grown on soil treated with sewage sludges follow the order: leaves>stem>cob>caryopsis (Page et al., 1979).

The toxicity caused by metals in the plant is the result of complex interactions between the metal ions, other essential or non-essential ions and environmental factors. It is highly likely that the phytotoxic mechanisms of a particular metal involve biochemical routes that differ depending on species and variety. The more general symptoms of metal phytotoxicity are chlorosis and cessation of development.

It has clearly been established that addition to the soil of a compost coming from undifferentiated collection of solid municipal wastes can bring about an increase in the total amount of the heavy metals in the soil. This type of compost, in fact, contains quite high levels of heavy metals, in particular lead. Long-term studies carried out in a vineyard where there had been application of a compost with a high heavy metal content, obtained from undifferentiated solid municipal wastes, and a compost with low heavy metal content, obtained from urban sludges and wood chippings (Pinamonti et al., 1999). Results showed in both cases an increase in organic matter, available phosphorous and exchangeable potassium. In addition, there was an improvement in porosity and water retention capacity. The application of the compost obtained from solid municipal wastes, however, resulted in an accumulation of metals in the soil, in the plant and in the must, whereas in the other case there were no increases in metals concentration Trials conducted in a plantation of Brassica chinensis where there was application of a compost obtained from industrial and sewage sludges and which contained relevant amounts of heavy metals, have shown an increase in pH, electrical conductivity and content in K, Ca, Mg, NH_4^+ and PO_4^{3-} in the soil. An increase of heavy metals in the plant tissues was also found, but only for cadmium the values were beyond the maximum allowed by the law (Wong et al., 1996).

In sesame plants grown on sandy soil the incorporation of a compost obtained from sludges, solid urban wastes and water hyacinths caused an increase in plant growth and increased their content of pigments, carbohydrates and mineral elements. The increase of heavy metals in the seeds was not enough to reach the values at which there are phenomena of phytotoxicity (AbdelSabour et al., 1996).

It is however worth underlining that, after the mixing of the compost with the soil of the arable layer, there were no particular phenomena of leaching of the heavy metals, which are often in a form that is unavailable for plant nutrition. It is difficult to foresee what the behaviour of these elements is in the long term. The role of organic matter is particularly important. In the initial phases, straight after application of the compost, there can be an increase in the bioavailability of the metals. This is due both to phenomena of rapid decomposition of the organic matter, with consequent release of soluble metals (Chaney and Ryan, 1993), and to an incomplete mixing of the compost with the soil. In this phase the soil-compost system is not balanced and the adsorbing properties of the system are not entirely effective.

The organic matter, on the other hand, depending on its molecular complexity, can withhold many metals, preventing diffusion towards the root system. This property is considered of relevant scientific interest and the results of various field experiments indicate that in soils treated with compost the content of heavy metals diminishes with time.

Conclusions

From an environmental point of view, the quality of the compost closely depends, besides the type of composting process, on the chemical characteristics of the original materials. A valid starting point is knowing the distribution of heavy metals in the various types of wastes. This enables us to prioritise the work to undertake for the separation of wastes and for an efficient source separated waste collection. In this way we can obtain a high quality compost with a limited content of pollutants. Moreover, in a 'low metal' compost the bioavailability of heavy metals is controlled by the compost chemistry. Till the adsorbing sites from compost are not saturated, the trace metals will not be able to exert a toxic effect or to accumulate in the plants, depending on their reactions with compost. With this kind of biomasses, the heavy metal uptake by plants will not increase despite an increase in metal loading (Dumontet et al 2001). Among these wastes, the organic fraction of selected solid urban wastes and the organic matter deriving from domestic, market, catering, food industry and agricultural uses, have a low pollutant content and can be used for the production of quality compost. Wastes with these characteristics have always been destined for use in agriculture and the soil has always benefited from interaction with wastes, efficiently carrying out its role as biodigester. It is important, therefore, that some types of wastes are separated so as to avoid negative effects on the protective functions that the soil carries out with respect to other environmental compartments, reserving the use in agriculture exclusively for composts that come from specific organic matrices selected at their origin. As regards the presence of heavy metals in the composts produced in Europe, it is worth pointing out that there has been a progressive reduction in the concentration of these elements in those composting processes where source separation is adopted.

As far as the legislation is concerned, we must assume an unbreakable commitment that this aspect is faced not from an emotive, but from a scientific point of view. This is only possible by having a clear knowledge of the chemistry of heavy metals in the soils treated with biomass, so that we can learn to live with these elements, with a view to a non-polluting use of compost. The production of compost, which contains many elements of fertility, is, in the vast problem of waste disposal, an environmentally correct choice as long as qualitative criteria are rigidly respected, starting from the type of materials used in the composting process.

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INFLUENCE OF THE STABILITY OF THE COMPOST ORGANIC MATTER ON THE DECAY OF ORGANIC POLLUTANTS DURING COMPOSTING AND IN SOIL AFTER COMPOST APPLICATION

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Introduction

Today only 7% of municipal wastes are composted in France but this waste management process is increasing. Most of the produced composts are used in agriculture and the farmers require guaranties on compost safety in terms of heavy metals, pathogens and organic micropollutants. The results presented here will focus on the organic micropollutants. Very few data are available on their concentrations in composts with only a few references on PAH and PCB concentrations. (Berset and Holzer 1995; Niederer et al. 1995; Grossi et al. 1998). More results are available on pesticides concentrations with usually very low concentrations detected (Fogarty and Tuovinen, 1991; Vogtmann et al., 1993; Strom, 2000; Buyuksonmez et al., 2000).

Few results are found in the literature on the behaviour of organic micropollutants likely to be present in compostable materials during the composting process. Fogarty and Tuovinen (1991) and Buyuksomnez et al. (1999) summarised the mechanisms of transformation of micropollutants (mainly pesticides) during composting. The dissipation of organic pollutants is mainly due to microbial degradation. Composting is characterised by the succession of various microbial populations: a) mesophilic microflora at the beginning of the process, b) thermophilic microflora when temperature reaches 45 to 70°C, c) second mesophilic microflora when temperature decreases and finally the maturation microflora. These different successive microflora could have various capacities to degrade organics pollutants. On the other hand, interactions with the organic matter could also participate to organic pollutants dissipation during composting. Sorption of organic pollutants on organic matter decreased their availability for microbial degradation. The initial physico-chemical interactions responsible for sorption can become non-reversible with time leading to the stabilisation of organic pollutants. The molecules become unextractable and it could explain their lack of detection in composts. Thus information on the behaviour of organic micropollutants during composting are needed including data on their mineralisation but also on the state of the residues after composting.

The objectives of this work were:

(1) to analyse polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) in French industrial composts
(2) to determine the potential mineralisation of PAHs likely to be found in compostable materials, during composting and to evaluate the respective participation of thermophilic and maturation microflora in pollutant mineralisation
(3) to determine the behaviour of the same organic pollutants in the soil after compost spreading.

Materials and methods

The composts

Composts were sampled in 11 different composting plants between 1998 and 2000: 2 greenwaste composts (GW1 and GW2), 2 biowaste composts (BIO1 and BIO2), 2 sludge and greenwaste composts (GWS1 and GWS2) and 5 municipal solid waste composts (MSW1, MSW2, MSW3 MSW4 and MSW5). BIO2 and GWS2 were sampled three times during the year 2000. GW2, BIO2, GWS2, MSW3 and MSW4 were sampled during the thermophilic and the maturation phases. A total of 24 compost samples was analysed. The composts were air-dried and ground before analysis (<250 mm). Their main characteristics are reported in Table 1.

Table 1. Main characteristics of the composts. The analysis are given in dry weight

Compost	Sampling		Age of	Ts	HA/	C_{org}	N_{kj}	C/N	pH
	phase	N°	sampling	°C	FA	(g/kg)	(g/kg)		water
GW1	Maturation	-	7 months	-	4.8	210	19	11.2	7.8
GW2	Thermophilic	-	3 weeks	68	0.7	280	13	21.7	8.2
	Maturation	-	3 months	<40	0.9	259	18	14.2	8.4
BIO1	Maturation	-	6 months	-	2.6	203	15	13.5	8.5
BIO2	Thermophilic	b	2 weeks	67	0.7	229	15	15.1	8.6
		c			0.8	269	19	13.9	8.4
	Maturation	a	3 months	<40	1.5	236	16	14.8	8.8
		b			1.2	304	19	15.7	8.0
		c			2.0	204	13.4	15.2	8.5
GWS1	Maturation	-	7 months	-	7.1	321	41	7.9	7.2
GWS2	Thermophilic	a	3 weeks	60	1.3	386	22	17.6	6.4
		b			1.6	375	26	14.4	6.7
		c			2.7	193	17	11.2	7.7
	Maturation	a	3 months	<40	2.2	257	22	11.7	7.5
		b			1.6	331	25	13.5	6.5
		c			2.4	236	22	11.0	7.4
MSW1	"Maturation"	-	1 month	-	0.1	285	18	16.1	6.5
MSW2	"Maturation"	-	3 months	-	0.3	330	20	16.8	6.6
MSW3	Thermophilic	-	17 days	60	0.3	385	11	35.3	6.5
	Maturation	-	3 months	<40	0.7	218	15	14.8	8.2
MSW4	Thermophilic	-	4 days	60	0.4	338	13	26.6	7.5
	Maturation	-	3 months	<40	0.8	283	13	21.8	8.3
MSW5	"Maturation"	-	3 months	-	0.3	330	20	16.8	6.6

Humic and fulvic acids were extracted in NaOH then fulvic acids (FA) were separated by acid precipitation of the humic acid (HA). Total extracted carbon was analysed before and after precipitation of the HA. The HA/FA ratio was used to evaluate the compost maturity: Composts were considered as mature when HA/FA was larger than 1 (Roletto et al., 1985; Chen and Inbar, 1993). Indeed the ratio increased during the composting process as shown by the results obtained when composts were sampled during the thermophilic and the maturation phase (Table 1). With this criterion, all the BIO, GW and GWS composts (GW2 excepted) were mature confirmed by the percentage of total organic carbon mineralised during the incubations (less than 15%, results not shown). The MSW compost remained unstable when sampled during the usual process (MSW1, 2 and 5) with more than 30% of total organic carbon mineralised during the incubations.

When the maturation phase was more controlled (MSW3 and 4) compost maturity increased with only 16% of total C mineralised but with a HA/FA ratio remaining below 1.

Total PAHs and PCBs analysis

Total polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were extracted by accelerated solvent extraction (Dionex ASE 200, CA, USA). Mixtures of 2 g ground compost and 5 g celite were extracted with acetone/dichloromethane (1/1) for 20 min at 100 °C under 10^3 - 10^5 Pa for PAHs and with acetone/hexane (1/1) for 20 min at 150 °C under 10^3 - 10^5 Pa for PCBs. The recovered volumes after extraction were 30 ml for PAHs and PCBs.

After extraction, 0.5 ml of n-dodecane was added to the PAH extracts to prevent volatilisation of the molecules, then the extracts were evaporated until 1 ml under N_2. The residues were recovered in 2 ml of hexane, then purified on a column filled with Al_2O_3 and eluted by hexane. The hexane solutions were concentrated as previously and recovered in 2 ml of acetonitrile. After filtration on cellulosic filters (0.45 mm, Sartorius, Minisart RCK), PAHs were analysed by HPLC with fluorescence detection (Ternary pump Varian 9012, Autosampler Varian 9100, column Hypersil Green PAH - 5 mm, 100 x 4.6 mm, detector Varian 9075). Volumes of 10 ml were injected. The mobile phase (2 ml min^{-1}) was a mixture of MilliQ water and acetonitrile. The gradient chromatography started with 50/50 water/acetonitrile (v/v) for 5 min, then gradually reached 100% acetonitrile during 25 min.

PCB extracts were evaporated as previously and recovered in 2 ml of hexane and purified by shaking in 10 ml of 18M H_2SO_4. The hexane solution was recovered, then rinsed with 20 ml of MilliQ water, then filtrated on anhydrous Na_2SO_4. Sulphur was eliminated from the extracts on 2 g of reduced copper. Then the extracts were evaporated as previously and recovered in 2 ml hexane. The extracts were analysed by gas chromatography (Varian 3400, autosampler Varian 8200, injector split/splitless at 300 °C Varian 1077 in splitless mode) on a capillary column DB-5 (0.25 mm, 30 m * 0.25 mm), with electron capture detection (300 °C). The volume injected was 1.5 ml and the gas vector was helium. The temperature was programmed as followed: 70 °C during 1 min, gradient of 18 °C min-1 up to 250 °C, then 250 °C during 5 min, gradient of 5 °C min-1 up to 280 °C, 280 °C during 8 min.

Potential degradation of PAHs by compost microflora.

Three composts were used: a biowaste compost (BIO2), a municipal solid waste compost (MSW3), and a green waste + sludge compost (GWS2). On each composting plant, two sampling were realised: one in the thermophilic phase (fresh compost) to attend the thermophilic microflora and one in maturation (ripe compost) to attend the maturation microflora. The mineralisation of 3 PAHs (phenanthrene, fluoranthene and benzo(a)pyrene), was measured during incubations at 60°C in fresh compost and in ripe compost at 28°C, under laboratory conditions. All molecules were ^{14}C-labelled (Table 2) which allowed the measurement of their mineralisation by trapping $^{14}CO2$ in NaOH. Their volatilisation was also measured by trapping on glass wool impregnated with paraffin oil.

To avoid any methanol effect on microbial cells in case of direct application of solution on compost, the methanol solutions of ^{14}C-PAH (500 µl) were applied to 250 mg of sand (Fontainebleau sand, Prolabo) in 100 ml jars. The jars were capped with glass wool impregnated with paraffin oil to trap the volatilised fraction of ^{14}C-pollutants. Then the methanol was evaporated at 35°C during 2 hours. The radioactivity trapped in the glass wool was measured by liquid scintillation counting (LSC) (Kontron Betamatic V; Kontron Ins, Montigny Le Bretonneux, France) with 10 ml of Ultimagold XR scintillation cocktail (Packard, USA). The residual radioactivities are reported in Table 2. After methanol evaporation, the sand was mixed with 5 g of fresh or ripe compost. The sand-compost mixtures were incubated in air-tight closed 500 ml jars. The $^{14}CO_2$ evolved during the mineralisation of the ^{14}C labelled molecules was trapped in 10 ml of 1M NaOH, which was placed in the jars. The radioactivity in the alkaline was measured by mixing 0.5 ml of the sodium hydroxide solution with 10 ml of Ultimagold XR scintillation cocktail (Packard, USA) followed by LSC.

Prior to incubation, compost water content was adjusted to 55% of wet weight (corresponding to the theoretic humidity in composting plants) with milliQ water. The water content of the sand compost mixtures was checked by weighing during the experiments and adjusted with milliQ water if necessary. Fresh composts were first incubated at 60°C during 12 days to simulate the thermophilic phase, then at 28°C during 30 days to simulate the maturation phase. The ripe composts were incubated between 30 and 140 days, depending on the compound under investigation and the compost type, to achieve a maximum of mineralisation at 28°C simulating the maturation phase. All the jars were capped with glass wool impregnated with paraffin oil to trap the volatilised fraction of ^{14}C-pollutants during incubations. The traps were replaced after the 12 days at 60°C. All the experiments were done in triplicate.

Table 2. ^{14}C-PAH solutions used for the incubations in fresh and mature composts and in soil-compost mixtures.

	PAH Molecules		Fresh and mature compost experiment		Soil-compost mixture experiment	
PAH	^{14}C localisation	Specific Activity (mCi.mmol^{-1})	Initial Radioactivity (Bq/ml)	Residual radioactivity (Bq)	Initial radioactivity (Bq/ml)	Applied radioactivity (Bq)
PHE[1]	C9	12.4	1957	836	29900	2990
FLT[1]	C3	45.0	1716	725	34480	3448
B(a)P[1]	C7	26.6	1781	890	47710	4771

[1] PHE : phenanthrene, FLT : fluoranthene, B(a)P : benzo(a)pyrene

Behaviour of PAH during incubations in soil-compost mixtures.

Other incubations with soil, composts and soil –compost mixtures were realised to simulate the behaviour of ^{14}C-labelled PAHs in soil after compost spreading. Three contrasted composts were sampled in order to be representative of those used by farmers: a municipal solid waste compost (MSW1), a biowaste compost (BIO1) and a greenwaste+sludge compost (GWS1).

The incubations were realised with 1g of undried compost at 28°C under laboratory conditions. Prior to incubation, compost water content was adjusted to 55% of dry weight (corresponding to the theoretic humidity in composting plants) with milliQ water. The ^{14}C-labelled PAH was applied in methanol solution (100 ml; Table 2). The $^{14}CO_2$ evolved during the mineralisation of the ^{14}C labelled molecules was trapped in 10 ml of 1M NaOH, which was placed in the jars and periodically replaced. The radioactivity in the alkaline was measured by mixing 0.5 ml of the sodium hydroxide solution with 10 ml of Ultimagold XR scintillation cocktail (Packard, USA) followed by LSC.

After 28 days, 20g of fresh soil (a loamy soil with 75% of silt, 19% of clay, 6% of sand, 1.2% of C_{org} and pH 5.5) was added to the composts and incubations were continued during 55 more days.

Control incubations of PAHs with soil only were also realised. At the end of the incubations, the extractable residual radioactivity was measured in 100ml methanol extracts by scintillation counting after overnight agitation of the mixture then centrifugation (0,5ml of extract mixed with 4 ml of scintillation cocktail, Picofluor, Packard). The non extractable radioactivity was analysed in the pellets after grounding. The analysis was done on 300mg of the soil-compost mixture after combustion (Oxidiser 307 Packard), recovering of the radioactivity in a mixture of Carbosorb and Permafluor then analysis by liquid scintillation counting.

Results

PAH and PCB contents in industrial composts

Polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) have been analysed in 24 composts made from different wastes including municipal solid wastes (MSW), green wastes (GW), green wastes co-composted with sewage sludge (GWS) and biowastes (BIO). The detected concentrations were always low, varying between 1 and 15 mg/kg dry matter for the total of 15 PAHs and 0.02 to 0.29 for the total of 7 PCBs (Table 3). Very few references on PAH and PCB concentrations in composts have been published. The detected concentrations were similar to the results reported by Niederer et al. (1995) and Berset and Holzer (1995) in Swiss composts with PAH concentrations varying from 0.8 to 21 mg/kg of dry matter. The PCB concentrations were also similar to these reported in the few available references (Vogtmann et al., 1993; Grossi et al., 1998). These concentrations were much lower than usually detected in sewage sludge (ADEME, 1995).

Table 3. Total PAHs and PCBs in the sampled composts

Composts	Total PAHs[1] (mg/kg dry matter)		Total PCBs[2] (mg/kg dry matter)	
	Thermophilic[3]	Mature[3]	Thermophilic[3]	Mature[3]
GW1	-	1.51	-	0.019
GW2	1.44	1.68	0.06	0.066
BIO1	-	11.19	-	0.034
BIO2 a		3.68	0.10	0.104
b	2.77	1.40	0.105	0.060
c	6.06	3.19		0.091
GWS1		1.02	-	0.035
GWS2 a	1.01	1.56	0.047	0.121
b	1.04	0.78	0.077	0.096
c	1.15	1.72	0.087	0.104
MSW1	-	1.94	-	0.057
MSW2	-	3.05	-	0.041
MSW3	3.69	4.99	0.124	0.247
MSW4	1.42	1.47	0.092	0.293
MSW5	-	3.21	-	0.081

[1] 15 PAHs have been analyzed: Acenaphtene (ANA), Fluorene (FLU), Phenanthrene (PHE), Anthracene (ANT), Fluoranthene (FLT), Pyrene (PYR), Benzo(a)anthracene (BaA), Chrysene (CHY), Benzo(a)pyrene (BaP), Dibenzo(a,h)anthrcene (BBA), Benzo(b)fluoranthene (BbF), Benzo(k)fluranthene (BkF), Benzo(g,h,i)perylene (BPE), Indeno(1,2,3,cd)pyrene (IPY).

[2] 7 PCBs have been analyzed: PCB 28, 52, 101, 118, 138, 153, 180.

[3] Some composts have been sampled during the thermophilic phase (thermophilic) and during the maturation phase (mature)

No clear relation was observed between the concentrations and the composted wastes. The results varied with the localisation of the composting plant (Niederer et al., 1995) with the largest concentrations in the BIO1 compost coming from an industrial area. The concentrations varied with the sampling on the same plant with no clear evidence of decrease during the composting process. More results would be necessary. Actually, French legislation for compost use in agriculture does not include criteria of PAH and PCB concentrations. But comparing the detected concentrations of phenanthrene, PHE, fluoranthene, FLT and benzo(a)pyrene, B(a)P which are the 3 PAHs mentioned in the legislation for sludge use in agriculture, the compost concentrations were fare below the maximum allowed concentrations of 5 mg/kg for PHE, 2.5 mg/kg for FLT and 2 mg/kg for B(a)P. The concentrations in PCBs were also below the maximum concentration allowed (total of 7 PCB<0.8 mg/kg).

Potential degradation of organic micropollutants during the composting process

When incubated in soil alone, PAH mineralization decreased with the complexity of the molecules. At the end of the incubations, up to 60% of phenanthrene was mineralized, but only 10% of fluoranthene and 1% of benzo(a)pyrene (Fig.1).

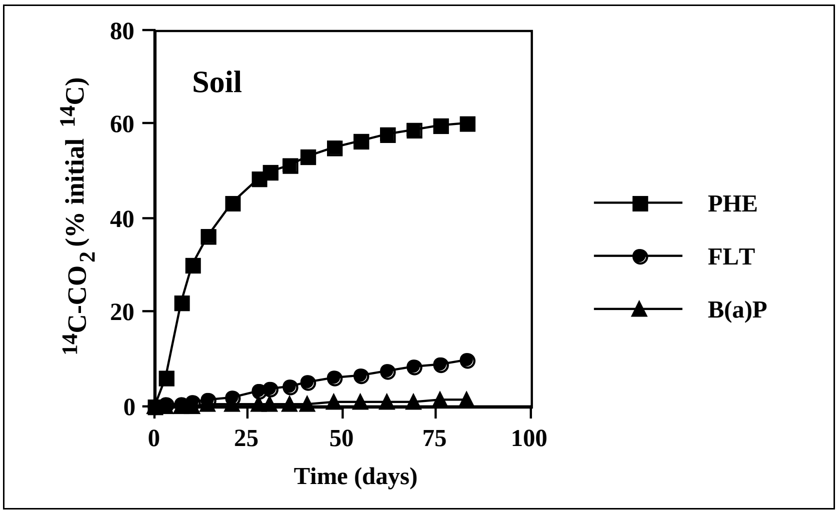

Fig. 1. Kinetics of PAH mineralisation during incubations with soil alone. Results are expressed in percent of the initial radioactivity added.

When incubated with the composts, large phenanthrene mineralisation (60%) occurred in the BIO, GW and GWS composts, but only 0 to 25% were mineralized in the MSW composts. In some composts, the microflora presented a larger capacity than soil microflora to mineralize fluoranthene with up to 60% of FLT mineralised with the BIO1 compost (Fig.2).

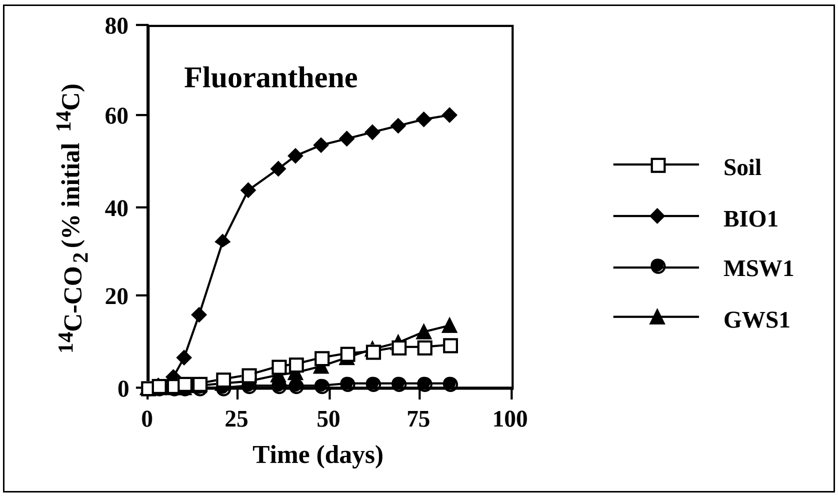

Fig. 2. Kinetics of fluoranthene mineralisation during incubation in soil or composts. Results are expressed in percent of the initial radioactivity.

When incubated in fresh and mature composts sampled on the same composting plant, mineralisation of the organic molecules was only observed when maturation microflora was present in ripe composts (Fig.3) as found by Martens (1982).

The absence of this microflora in fresh compost could be related to the destruction of PAH degraders at temperature exceeding 60°C mentioned by Potter et al. (1999). Mineralisation of phenanthrene and fluoranthene reached 50-70% in all ripe composts. Benzo(a)pyrene was mineralised (30%) only in the MSW ripe compost. No clear difference in degrading capacity appeared among the different composts, the major difference resulted in the larger mineralising capacity of the maturation than thermophilic microflora.

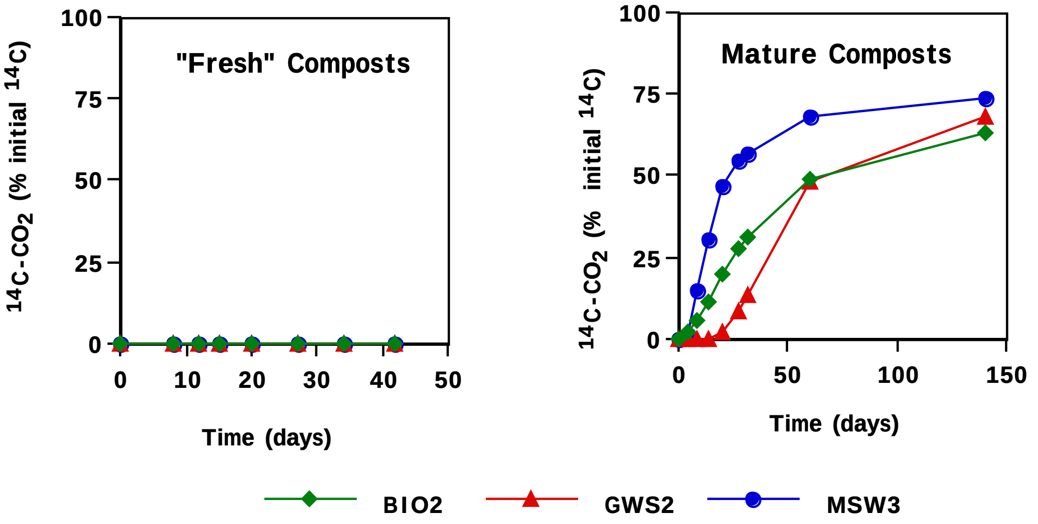

Fig. 3. Compost maturity conditions the presence of a microflora degrading organic micropollutants : example of ^{14}C-fluoranthene mineralisation in 3 « fresh » and « mature » composts sampled in the same composting plants.

Behaviour of organic micropollutants in soil after compost application : influence of compost maturity on the dissipation

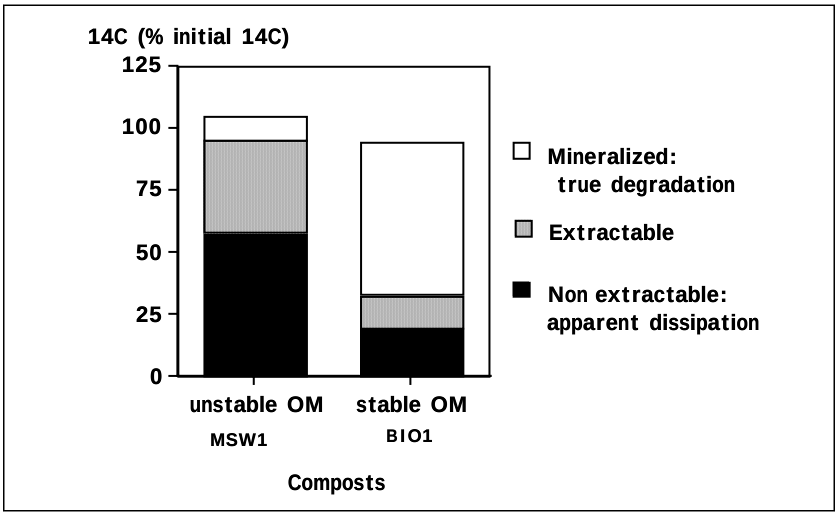

Fig. 4. Distribution of the initial ^{14}C added between the mineralized, extractable and non extractable fractions, at the end of the incubations of ^{14}C-fluoranthene in soil-compost mixtures. Influence of compost organic matter stability on the dissipation pathway of ^{14}C-fluoranthene (mineralisation or formation of unextractable residue) during soil-compost incubations

Some composts have been characterised by the presence of a microflora able to mineralize organic micropollutants which were not mineralised by soil microflora (example of ^{14}C fluoranthene in Fig. 2), in relation with their maturity. In soil-compost mixtures, organic micropollutant mineralisation was observed when mature composts were added to the soil (example of BIO1 in Fig.4). In these mature composts, the organic matter was rather stable and low mineralisation of organic carbon occurred during incubation.

When immature composts were added (large mineralisation of organic matter during incubation with OMG1), organic pollutant dissipation occurred also but mainly through formation of unextractable residues.

Conclusions

PAH and PCB concentrations have been analysed in 24 samples of industrial urban composts. The results pointed out low concentrations without clear relations with the composted wastes. The detected concentrations were always lower than the maximum concentrations allowed by legislation for sludge use in agriculture. More references of analysis are needed to evaluate the variability of the concentrations during the year on the same composting plant.

Dissipation of organic pollutants occurred during the composting process. However, the maturation microflora had a larger capacity than the thermophilic microflora to mineralise the organic pollutants. The maturation phase appeared to be an important phase in terms of degradation organic pollutants and it has to be carefully controlled in composting plants. On he other hand, the addition of immature composts to soil would favour the dissipation of organic pollutants via the formation of unextractable residues. More information about the behaviour of these unextractable residues is needed. How is the organic pollutant in these unextractable residues (mother molecule, metabolites)? How fast these residues will be released via the degradation of compost organic matter?

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ORGANIC MATTER EVOLUTION AND AVAILABILITY OF METALS DURING COMPOSTING OF MSW

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Introduction

Organic wastes are important sources of organic matter to improve soil physical, chemical and biological properties and the appropriate recycling of these products through soil and land applications could prevent water pollution, improve soil carrying capacity and crop nutrition (Dumontet and Chaussod, 1997, Dumontet et al. 2001), At the same time, the agricultural use of municipal solid waste (MSW) compost can bear with environmental risks which involve both the deterioration of soil quality and yield reduction of products due to immature compost, leaching of nutrients and undesirable substances, such as toxic elements which may be taken up by plants.

Many countries have established rigid standards based on the total content of elements in organic amendments, but many studies shown that chemical forms of trace elements are more important in determining their availability for plant uptake or leachability into the groundwater than the total concentrations in soil, amendments and amended soil (Petruzzelli et al.1989, McBride et al.1997). In particular, elements are present in a variety of chemical forms in the composted matter relying on reactions including complexation. Organically complexed metal species are common in biological matrices and, in addition, complexed chemical species are also formed during the microbial turnover process during composting (Hung Hsu and Lien Lo, 2000, Parè et al. 1999, Leita et al. 1999).

Organic matter serves as an important ligand to metals. In particular, dissolved organic matter (DOM), being the most mobile and biologically active soil organic fraction, increases the bioavailability and mobility of trace elements in the soil, while insoluble organic complexes can effectively remove metals from the solution and thus reduce their ecotoxicology (Zsolnay, 1996, Kaschl et al., 2002).

Concerning the MSW compost problems, the importance of organic matter evolution and relations among trace metals, humic and non-humic fraction of dissolved organic carbon (DOC) were investigated.

The experiment was carried out in an attempt to elaborate the CaCl2 soluble fraction of Cd, Cu, Ni, Pb and Zn in relation to transformations of organic matter, specifically of its soluble fraction during the composting of MSW.

Materials and methods

Composting was performed in turned pile (1t) regularly adjusted and monitored for environmental conditions (temperature and relative humidity). Samples were taken throughout 140 d of composting, at a mean depth of 40 cm, oven dried at 70°C and crushed to pass a 2mm sieve. The following parameters were determined:

- pH (H_2O)
- C/N ratio (total N and total organic C by dry combustion)

- Aqua regia extractable metals (microwave digestion system; ICP-OES, Leita et al. 1995, 1999)
- 0.1M $CaCl_2$ extractable metals (1:10 w/w, shaken for 3h under N_2; ICP-OES)
- Dissolved organic carbon (DOC) in the 0.01M $CaCl_2$ extract (1:10 w/w, shaken for 12h under N_2)
- Humic (humic and fulvic acids, HA+HF) and non-humic (NH) substances (De Nobili and Petrussi, 1986).

Results and discussion

As reported in Table 1, results showed typical trends of temperature, pH and C/N during the composting process. In particular, the C/N ratio, which reflects OM decomposition and stabilization of organic matrix, showed a high rate of change during 60 d (from 28 to 18), and reached a plateau (C/N 12) after the 62nd day of composting.

Table 1. Temperature, pH and C/N during the composting phases (mean ± std dev)

	Composting phases				
	initial	*thermophilic*	*mesophilic*	*maturing*	*curing*
T (^{0}C)	31 ± 0.6	72 ± 1.1	40 ± 0.7	20 ± 0.3	18 ± 0.2
PH	6.0 ± 0.1	8.7 ± 0.1	6,8 ± 0.1	7.2 ± 0.1	7.2 ± 0.1
C/N	28 ± 0.5	27 ± 0.4	18 ± 0.3	14 ± 0.2	12 ± 0.1

As reported by many authors (e.g. Chen and Inbar, 1993, Chefetz et al., 1996, Kaschl et al., 2002), the percentage of $CaCl_2$-extractable DOC vs TOC was about 3.5 % at the beginning of the composting, decreased the most during the initial phase of composting and declined slightly to 0.5% after the mesophilic phase (relationship: y=2.88x-0.58 r2=0,86).

The characterisation of DOC during the process showed a significant increase of humic fraction and a stepwise decrease of non humic. In particular, non humic fraction, mainly composed of amino acids, soluble polysaccharides, oligopeptides and proteinaceous materials with N-containing groups, was as much as 90% of the DOC, during the first days of composting, decreased rapidly during the thermophilic phase, reaching a constant percentage of about 8% thereafter. A concomitant increase of humic fraction was observed during composting, which was about 72% of DOC in mature and curing phases.

At the beginning of the experiment, the contents of each metal extracted with aqua regia was 30 mg kg^{-1} Cd, 165 mg kg^{-1} Cu, 86 mg kg^{-1} Ni, 186 mg kg^{-1} Pb, 480 mg kg^{-1} Zn, and increased slightly with composting time, together with a concurrent slow decrease of the organic matter.

The $CaCl_2$ solubility of all metals was greater within the first week of composting, when pH was still below the neutrality and decreased thereafter. In particular, we found that the soluble fraction of Cd and Zn decreased significantly with composting (Fig. 1a, 1b), whereas the solubility of Cu, Ni and Pb was low just after the thermophilic phase, and close to the detection limit in mature compost.

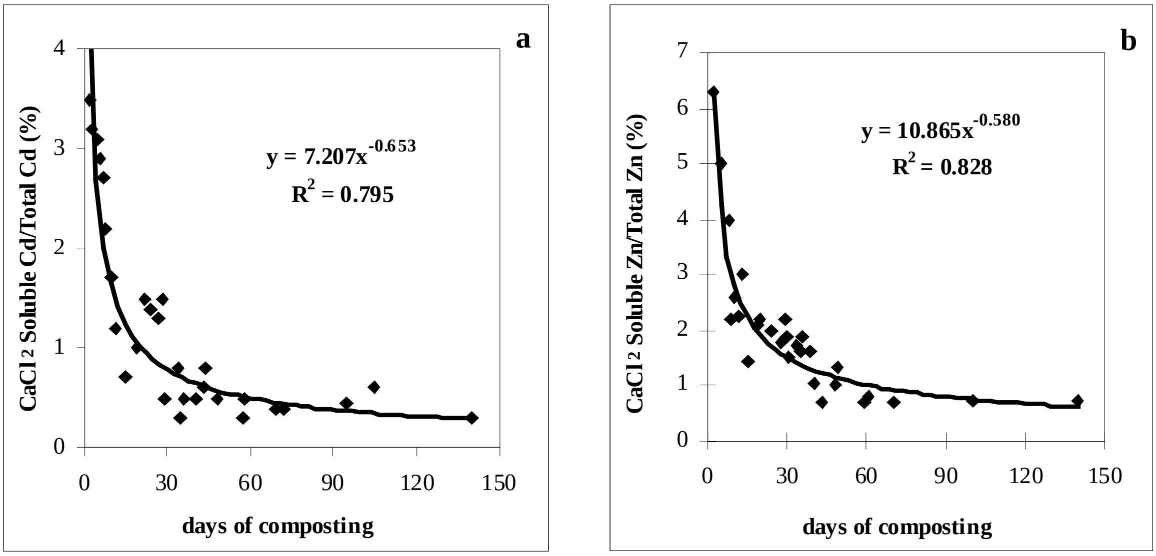

Fig. 1. Soluble fraction of Cd (a) and Zn (b) during composting .

No relationship was found between pH and extractable fractions of all metals, even significant amounts were still extracted during the thermophilic phase, when pH of the composting material was alkaline, and this fact can be attributed to enhanced formation of metal-soluble organic ligand complexes.

As the chemical composition of $CaCl_2$ extracts changed with time, relations among soluble metals, humic and non humic fractions of DOC were studied.

The $CaCl_2$ extractable fractions of Cd, Zn were highly correlated with non humic substances of DOC only (Fig. 2a, 2b).

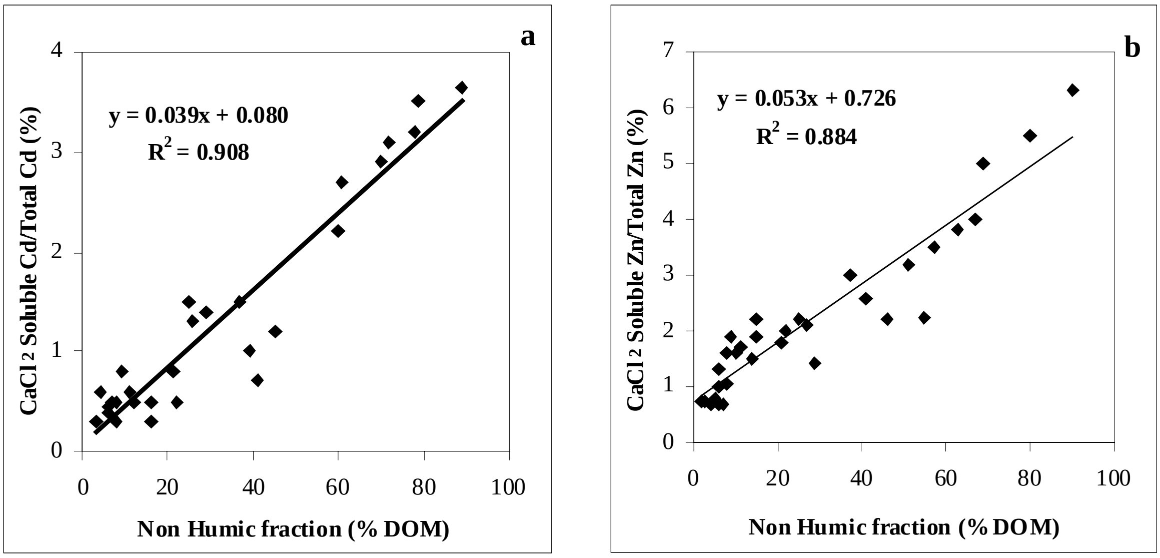

Fig. 2. Correlation of soluble fraction of Cd (a) and Zn (b) with non-humic substances.

A different behaviour was found for extractable fractions of Cu, Pb and Ni, which were significantly correlated with the soluble humic substances characterised by higher selective affinity to metal complexation (Fig. 3) (Kaschl et al. 2001). As previously reported by Leita and De Nobili (1991), the ability of Cu to form metal-humic complexes is probably due to its chemical affinity toward N-functional groups of humic fraction, and therefore, to the ability of Cu ions to saturate the complexing capacity of dissolved humic substances. In this experiment, a similar behaviour was also observed for Pb and Ni, whose relationships were : Ni: $y = 1.54 + 1.87x$ ($r = 0.93$ **) and Pb: $y = 0.061 + 0.096x$ ($r= 0.97$**), respectively.

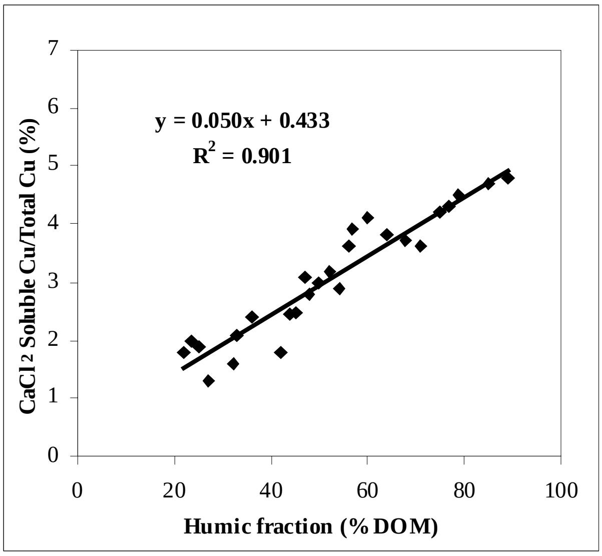

Fig. 3. Correlation of soluble fraction of Cu with humic substances.

In summa, the degree of stabilization reached by organic matter appears to be important in determining potential mobility, availability of heavy metals. In particular, the chemical behaviour of metal complexation appear to be closely related to the quality of organic matter in organic matrices.

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RISK OF HEAVY METAL POLLUTION OF SOILS DURING APPLICATION OF COMPOSTS

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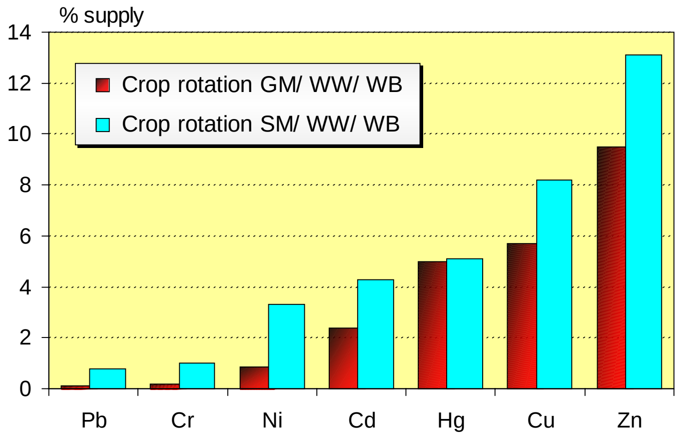


Fig. 1. Relation between uptake of heavy metals by harvest products and supply of heavy metals by composts;

Compost application rate 6 – 10 t DM ha^{-1} y^{-1} Crop Rotation: SM- Silo-Maize, GM – Grain-Maize, WW – Winter-Wheat, WB – Winter-Barley

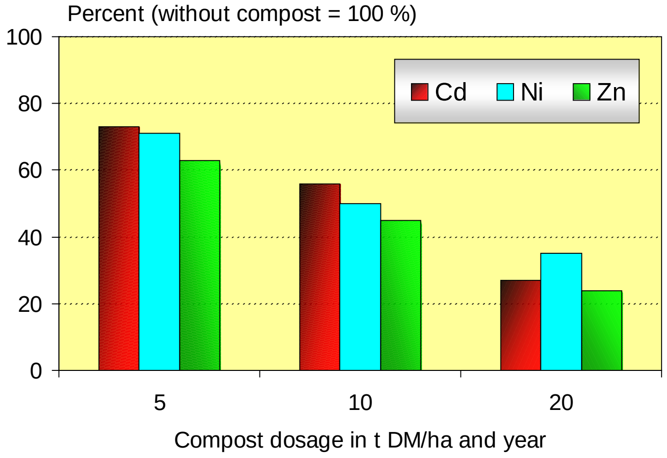
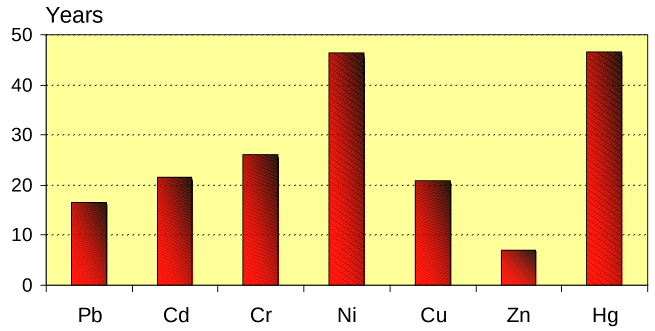


Fig. 2. Mobile heavy metal contents of soils in relation to compost dosage

(relative terms: control without compost = 100 %) Soil extraction with 1M NH_4NO_3

In field tests for compost application over several years, which are carried out since 1995 in the Land of the Federal Republic Baden-Wuerttemberg on six typical field locations, also the consequences of heavy metal dosage supplied with annual compost application on the heavy metal contents of harvest products and soil were examined.

The heavy metal contents of the harvest products up to now remained unaffected by the compost application. The very small heavy metal uptake of the harvest products amounts to max. 10 - 15 % of the heavy metal supply with composts (see Fig. 1). Thus - although low - a positive balance of heavy metals still remains in soil. As a result the total contents in soil were not raised up to now. The mobile heavy metal contents of Cd, Ni and Zn even decreased with rising application of com-posts (see Fig. 2). 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 (see Fig. 3). Therefore the risk of a heavy metal pollution of soil is low and tolerable as long as moderate compost dosage less than 10 t/ha dry matter is applied annually.



Heavy metal soil contents in mg/kg

Mean	30	0,20	30	30	20	50	0,20
Increase	1,5	0,02	1,5	1,5	2,0	2,5	0,02

Fig. 3. Period of time for measurable increase of heavy metal soil contents

Based on:
a) Mean heavy metal freights of compost dosage of 6-7 t DM ha^{-1} y^{-1}
b) Mean: heavy metal contents of soils
c) Increase: smallest analytically measurable increase of h. m. content

THE VALUE OF COMPOST

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Introduction

One of the main problems confronting producers of compost is that end-users are not prepared to pay an economical price. As things stand, this can only get worse, since increasing production will result in supply exceeding demand. There is no point in basing an expansion programme on a price now obtainable (already low) if this is sure to fall as a result of the expansion. The only way to achieve a higher price for compost is to convince users that the benefits are greater than they at present realise.

Attempts have been made to calculate a value based on the nutrient content (N, P, K, etc.) as compared with artificial fertilizers, and this could, with some effort, be increased by adding the value of the magnesium, sulphur, boron, etc. The disadvantage here is that, when derived from compost, these elements cannot be applied separately: they come as a package, in fixed proportions, and are spread on the land whether they are needed or not. They may or may not have a value to the farmer at the time of application. The costs of storage, transport and spreading are considerably greater for compost, with its much larger volume than the equivalent artificial fertilizer. It is clearly difficult to justify a high value for compost, based solely on the nutrient content.

One way of increasing the value is to manufacture a compost with considerably higher nutrient levels than that produced from, e.g., green waste. This can be done, by using high-nitrogen feedstocks, such as poultry manure, protein-rich seed, fish and meat wastes, or even explosives. The product is a fertilizer produced by composting, rather than a compost as usually understood (the dividing line between the two is difficult to define). Such material will give an immediately-visible increase in plant growth, and users are, therefore, prepared to pay a much higher price than for a low-nutrient compost. Transport and spreading costs are much lower for a given nutrient content. The purpose of the composting operation, in this case, is to manufacture a product, not to dispose of a waste.

This kind of “organic fertilizer produced by composting” can never be more than a relatively-small part of the whole compost market, and some way must be found to convince end-users (and the regulatory authorities) that large-volume compost is a valuable product.

The value of the nutrient-element content is not, alone, a sufficiently convincing factor (although, if long-term environmental consequences were included, it could be so). There can be no dispute that compost is very valuable as a soil-improver, in maintaining or increasing the organic-matter content of soils, which in many agricultural areas has fallen to unacceptable levels. It can also be used to make soil, by mixing with mineral substrates - subsoil, sand, clay, shale, etc., and to clean contaminated soils. The problem here is that there is no easy way of calculating the value of the effect on soil quality. Comparisons can be made between the costs of on-site soil manufacturing and the importation of topsoil, or between competing methods of soil decontamination, but these are only short-term figures. There is no satisfactory basis for estimation of the long-term value of a good soil. A very important point, which may not be generally recognised, is that one application of compost can rescue or create a soil, and that this is a permanent change, the benefit being felt in each subsequent year. Furthermore, in many cases the application of compost is the only feasible way by which this improvement could be achieved, and this should be reflected in the value attributed to it.

Some examples of the use of compost (in this case a composted fertiliser, “Envigro”, derived mainly from poultry litter) to convert sterile materials to soil are described below.

A Carboniferous (Coal Measures) shale

This was exposed (for the first time in 300,000,000 years) in a road cutting. Organic matter, in the usual sense, is absent but there are some carbonaceous (coal) fragments, and iron levels are high. The shale, once exposed is readily weathered, so that whilst normal pedogenic processes would eventually, after many decades, produce a soil, the steep slopes of the cutting are unstable, and plants cannot take root.

Two plots were marked out, and raked to a uniform slope of 30º. A layer of compost 5mm thick was spread on one plot, and raked in to a depth of 30mm. Both plots were then seeded with lawn grass.

After 7 months the fertilized plot was indistinguishable from control plots on fertile soil. Grass cover was complete, and the growth was very vigorous. The worm count was c. 100 per square metre. On the untreated plot grass covered only c.10% of the area, and was of very poor colour and vigour. There were no worms.

After a further twelve months the treated plot had a 100% plant cover, with at least ten self-seeded broad-leaved species. The untreated plot had, as a result mainly of frost weathering of the bare surface during the winter, reverted to an unstable shale slope, with very little vegetation.

A further similar trial, where a combination of peat and a granular artificial fertilizer was used instead of compost, gave an initial improvement, but, after 12 months, results were very little better than that from the shale-only plot. The compost was clearly much superior as a soil-creating material.

This can be explained by the fact that the compost provides a combination of organic matter and nutrients bound within it and released as required by the plants, resulting in a permanent and self-sustaining increase in fertility. When a compost with very large numbers of micro-organisms is added to a sterile substrate, many will survive to multiply in the resulting soil, and will be followed by a prolific soil microflora and fauna.

An extremely acid sand

Late-glacial sand dredged from the bed of a lake is screened to remove large particles and peaty and woody fragments. This reject material is stockpiled, and large amounts can accumulate over the years. When attempts were made to use this sand as a growing-medium, it was found to be extremely toxic to plants. Analysis showed it has a pH of 2. This was shown to be derived from iron sulphides which had been formed in permanently saturated and completely anaerobic conditions, and were oxidized on exposure to the air, forming sulphuric acid.

It was found that several years of normal weathering are needed to reduce the acidity to a non-phytotoxic level. As the acid is washed out by rain, more is formed from the remaining sulphides, until they are exhausted.

Compost was mixed with the sand, in the ratio of six sand to one compost, by weight. After 20 days, the pH of the mixture was 5.8. Grass seed was then sown in both the compost-treated sand and untreated sand. In the former, growth was equal to that in a fertile soil control, whilst in the latter no seeds germinated.

In this case it would appear that the ameliorating effects are due to the very high surface area of particles in compost, giving very high adsorption, and the high buffering and cation-exchange capacities. The combination of these properties with the nutrient content and the high microbial activity are unique to compost.

It is clear that, in many instances, compost can be used to solve problems which cannot be dealt with in any other way, or in no other cost-effective way. This should be recognised in the price which users are prepared to pay, but as there are no accepted values for the long-term preservation of soil fertility or the long-term benefits of soil formation or decontamination, users of compost will be interested only in obvious very short-term benefits.

There is a need for governmental or other bodies to give some guidance or suggestions as to what might be in the long-term national interest, in respect of preservation of soil fertility, nutrient recycling, etc., and what these are worth, per hectare per year.

There is also a need for a more sensible approach to possible legislation regarding compost use, spreading rates, etc. There is a danger that this will be based on worst-case figures for heavy-metal levels, nutrient-loading, etc., with little or no consideration of what might be the best solution to the particular problem.

There could, for instance, be a problem of soil contamination, or of erosion, or there might be an urgent need to reclaim and make fertile a barren site. The best solution to that problem could be a very heavy application of compost (150t or more per hectare) and it would be foolish to impose a less-effective and higher-risk method simply because of a regulation drawn up to cater for purely theoretical objections. There is a danger that the use of compost will be so restricted that other, less satisfactory and higher-risk solutions will be employed, simply because they have not yet been subjected to the same over-scrutiny which has affected composting.

Session V

Meliorating physical properties – how effective is compost?

INTRODUCTION

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Introduction – Influence of soil organic matter on physical properties

Among the influence on chemical properties such as nutrient balance, buffer capacity or pH compost is attributed benefits to physical properties like

- soil structure and aggregate stability
- hydraulic conductivity
- infiltration and erosion
- field capacity
- air balance
- soil temperature

Significance of organic matter for soil physical properties

Soil organic matter (SOM) in general and compost in particular primarily take effect through their influence on aggregate stability. Soil structure and aggregate stability are improved by SOM through its effects as `glue`-substances. SOM of different compounds like humic acids, polysaccharides, fungal hyphae and roots associates particles and smaller aggregates of different size to stable aggregates. Microaggregates less than 20 µm are mainly stabilized by clay minerals with support of high molecular organic aromatic compounds and metabolic products of microorganisms whereas aggregates from 20-250 µm additionally are stabilized by roots and fungal hyphae. For the stabilization of macroaggregates (> 250 µm) plant residues and applied organic matter are of importance and this can mostly influenced by cultivation (Fig. 1). Supply of organic matter especially compost to soils stabilizes aggregates on three significant ways:

- supply of organic matter supports the microbial activity and thereby the production of metabolic products with cementing properties
- supply of organic matter supports the activity of earthworms. Their excrement aggregates also have positive effects on the soil structure
- supply of high molecular humic acids improve the long term stability of micro-aggregates.

Hydraulic conductivity is mostly influenced by pore volume and pore size distribution and so that by corn size distribution. In addition to primary pores secondary pores like root and animal tubes matter for hydraulic conductivity especially in top soils. A good soil structure and aggregate stability also contribute to formation of secondary pores. Applied organic matter therefore takes a directly effect to formation of secondary pores as food supply for soil fauna like earthworms and an indirectly effect by stabilisation of soil structure.

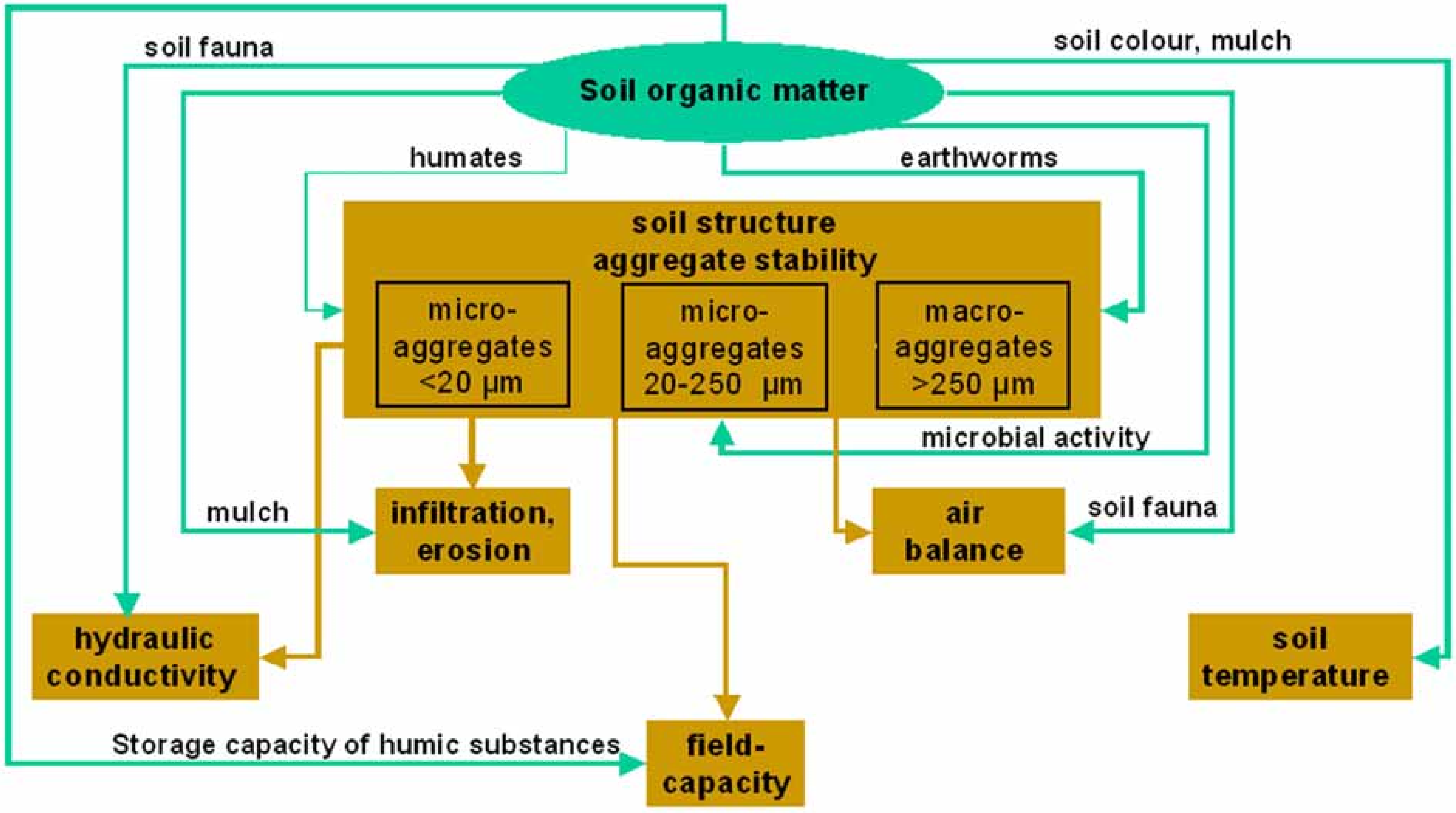


Fig. 1. Significance of humic substances for soil physical properties

Infiltration depends on hydraulic conductivity. At rainfall infiltration decreases due to destruction of aggregates, slaking and incrustation and erosion increases. Organic substances and also larger aggregates decelerate disaggregation and reduce erosion. Aggregate stability and size can be increased by application of organic matter and with it the infiltration. Organic matter which is applied on the soil surface reduces erosion directly by cover the surface and buffering a part of rainfall energy.

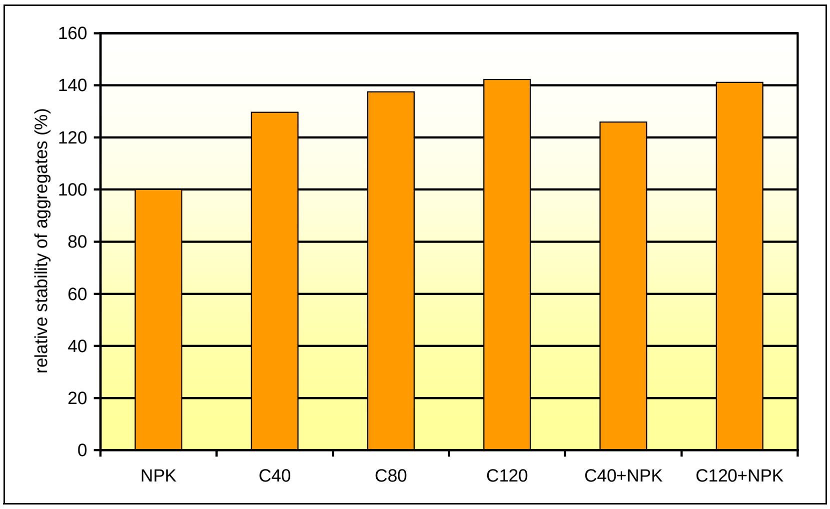
Field capacity specifies the amount of water which can be stored by a soil and depends predominantly on pore volume and pore size distribution. Organic matter improves primarily in sandy soils and clay soils the formation of secondary pores by formation and stabilisation of aggregates and the high storage capacity for water.

Air balance is determined by coarse pores > 50 µm. Therefore sandy soils have a good aeration because of the high amount of coarse pores as a result of corn size distribution. In contrast clay soils often have a low aeration. Organic matter improves primarily in clay soils the air balance by formation and stabilisation of aggregate structure and as food supply of animals like earthworms.

Soil temperature is influenced by organic matter on the effect of soil colour. With increasing amounts of organic matter in soil the soil colour gets darker and this increases the adsorption ability for radiation and accelerates the heating of soils.

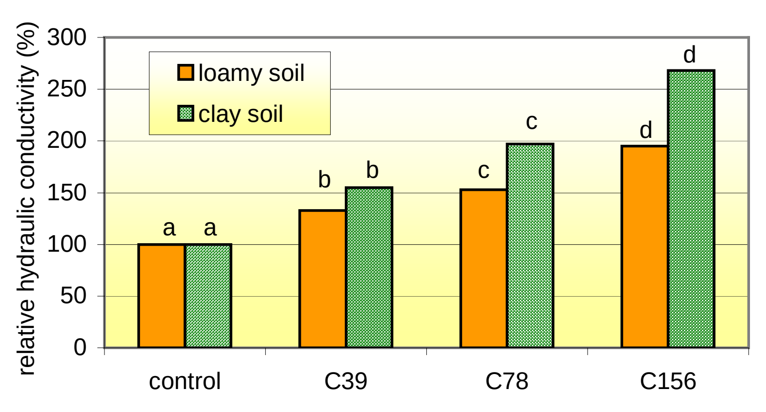
Effect of compost on physical properties – results from literature

The literature study does not provide an explicit result. The most investigations indicate an improvement of aggregate stability and other soil physical properties. Martins & Kowald (1988) showed a significant increase of aggregate stability by use of compost (Fig. 2) yet by the lowest amount of application. With higher amounts there is no more significant increasing of aggregate stability. Aggelides & Londra (2000) found a significant increase of hydraulic conductivity and field capacity after application of compost especially in a clay soil (Fig. 3). Some other authors (e. g. Lamp, 1996, Mbagwu & Piccolo, 1990) reported similar results but not all could ensure the results statistically. Even if they found a statistically significance, this was often first by high amounts of applied compost which were much higher than in practical use. And some studies like Asche et al. (1994) could not find an influence of compost on soil physical properties.



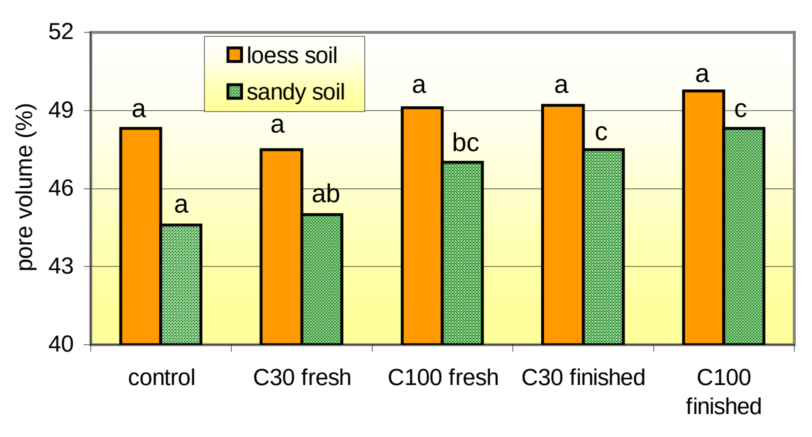
NPK: only mineral fertilizer, C40 – C120: 40, 80, 120 t/ha, C40/C120+NPK: compost+mineral fertiliser)

Fig. 2. Relative stability of aggregates by different amounts of compost application (Martins & Kowald, 1988)



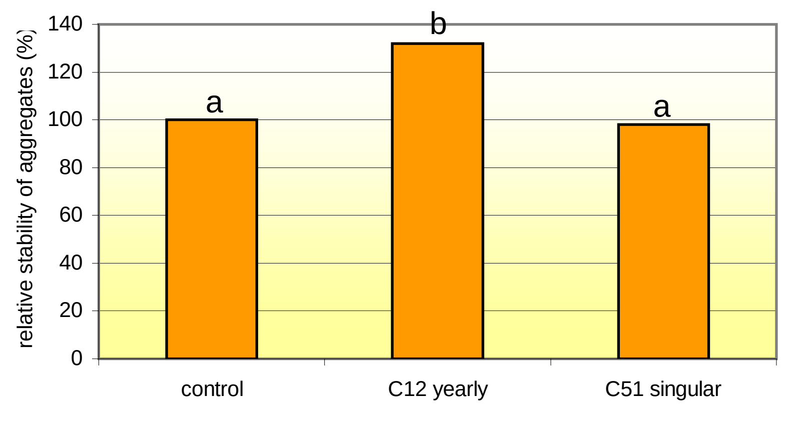
control: no compost, C39-C156: amount of application in tons, different letters indicate significant statistic difference

Fig. 3. Relative hydraulic conductivity at different amounts of compost application in two soils (Aggelides & Londra, 2000)



control: only mineral fertiliser, C30/C100 amount of application in tons, different letters indicate significant statistic difference

Fig.4. 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

Fig. 5. Relative stability of aggregates at different amounts and types of compost application (Lamp, 1996)

This and the results from other authors let suppose that not only the amount of applied compost is important for the effect of compost fertilisation but also the type of compost (fresh or finished compost), the interval of application and especially the soils on which the compost is applied. Some investigations (e. g. Petersen & Stöppler-Zimmer, 1996) determined a better effect of finished compost on aggregate stability and pore volume compared with fresh compost, whereby this difference was noticed especially by sandy soils (Fig. 4). 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 (Fig. 5).

Summary

The stability of aggregates is the most important parameter for the viewed soil physical properties. The application of compost shows mostly positive effects on aggregate stability and other physical properties. But it is to suppose that the effect on aggregate stability is mainly applied to an influence on macroaggregates and microaggregates > 20 µm because of the slow turnover rate of organic compounds which influence the stability of small aggregates and the important role of clay minerals which can not be influenced by cultivation. It is reasonable that the application of external organic matter can improve the soil structure especially of sandy or cohesive (clayey) soils.

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RUNOFF, SOIL EROSION AND RELATED PHYSICAL PROPERTIES AFTER 7 YEARS OF COMPOST APPLICATION

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Introduction

Compost is known to influence various properties of soils in a positive way. In this context, most of all, aspects of soil fertility have been studied alongside the application of compost. Additionally, the alteration of the soil organic matter status should positively influence also a variety of other soil properties. Schoemakers (1985), Martins and Kowald (1988) and Giusquiani et al. (1995) all report a positive influence of refuse compost on various soil physical properties. Others obtained contradictory results (Weinfurtner, 2002). Similar differences can be found for the effect of compost application on soil erosion. Theoretically, both the soil chemical and the soil physical status influence the erosion susceptibility of a site and therefore their improvement through application of compost should also have an effect on soil resistance against soil erosion. Using rainfall simulation experiments, Klaghofer and Spiegel (1990) tested the effect of refuse compost on soil loss in vineyards three years after application. Their results indicate no positive effects on soil erosion control, though measurements of erosion at natural rainfall showed somewhat different results in the first year after compost application. Bazoffi et al. (1998) investigated effects of refuse compost application on various soil physical parameters and soil erosion in a three year study. They report a positive effect on soil bulk density for the first year after application. For the following years, effects were less pronounced. Soil erosion differed only for one year out of three. On the other hand, Siegrist et al. (1998) applied various tests of erosion susceptibility to long term organically farmed soils. They conclude, that erosion susceptibility was higher on conventionally farmed soils compared to soils where organic farming had been practised, though particular measurements of their different tests did not always exhibit the same trend. As compost qualities differ a lot depending on the raw materials used, this may be one reason for the contradictory results. Another explanation may be the temporal limitation of many experimental layouts. It may also be hypothesised, that management strategies of compost application influence the results, i.e. a one time application of compost with a high application rate may be less effective in terms of organic matter management compared to annual applications with smaller application rates.

To gain insight into effects of compost application on the whole set of soil chemical, physical and microbiological properties in the long term, a field experiment was set up in 1993 at sites of the Agricultural College “Ritzlhof” near Linz, Upper Austria. An additional experimental question was whether different practices of compost preparation would have beneficial effects on soil quality. As a part of this study rainfall simulation experiments were carried out to determine possible effects of compost on erosion susceptibility and soil physical properties that may be related to it.

Experimental Layout and Methods

Experimental Layout

The setup of the whole experimental field consists of plots of 25 x 12 m with 4 treatments (and 4 replicates each) of compost prepared in different ways and 12 control plots of the same size. Compost is applied annually with an amount of between 30 and 50 m^3 which corresponds to between 12 and 24 tons dry matter (depending on densities and water contents of the different composts). Details about the experiment and first results on physical, chemical and microbiological response to composting treatments can be found in Weissteiner (2000). For the rainfall simulation study two different compost treatments were used and compared to the control. Table 1 details the different ways of compost preparation.

Table 1. Treatments studied for the rainfall simulation experiment

Treatment	Management
Control	conventional management without compost application
Standard compost	management with application of compost prepared in a way typically used by farmers - “bäuerlicher Mischkompost”
CMC compost	management with application of compost which had been prepared with the same raw materials as standard compost but processed with special care on temperature and water content. In addition this compost received a mixture of bacteria at the start of preparation to facilitate turnover

Rainfall simulations were carried out in spring 1999 on plots of a size of 2 x 5 m and prepared to seedbed conditions. The soil of the experimental field can be classified as “pseudovergleyte Lockersediment-Braunerde” (Fink, 1969). Table 2 indicates some basic soil properties analysed at the start of the experiment (Weisssteiner, 2000).

Table 2. Basic properties of the soils of the experimental field

Depth cm	**Sand** %	**Silt** %	**Clay** %	**pH** $CaCl_2$	**$CaCO_3$** %	**Org. C** %	**P_2O_5 (CAL)** ppm	**N** %
0-20	17	60	23	7.0	0.4	1.1	290	0.18

Methods

The rainfall simulator consisted of two modules, each equipped with 3 nozzles which are driven by electronically controlled solenoid valves. The simulator produced median volumetric drop sizes of 2.0 mm with a uniformity of 90% (Christiansen, 1942). Mean kinetic energy of the drops was about 17 $J/m^2/mm$. Further details of the simulator can be found in Strauss et al. (2000). Fig. 1 gives an overview about the set up for rainfall simulation. Prior to the main experiment, 30 mm of rainfall were applied to avoid variations due to different water contents of the plots. During this presimulation, the plots were covered with a dense mesh to preserve the plot surface. For the main experiment, rainfall was applied with an intensity of 1 mm/min for 60 min. Runoff and sediment were collected in buckets. In addition, undisturbed soil samples were taken after the rainfall simulation for analysis of bulk density and saturated hydraulic conductivity. Bulk samples were taken from each plot to analyse for soil texture and organic carbon. Results for bulk density and saturated hydraulic conductivity are given as means of 6 cylinders(200 cm3)/plot. Rainfall simulations were performed with three replicate at the standard and two replicates for each compost treatment.

Results

Fig. 1. The rainfall simulator at work

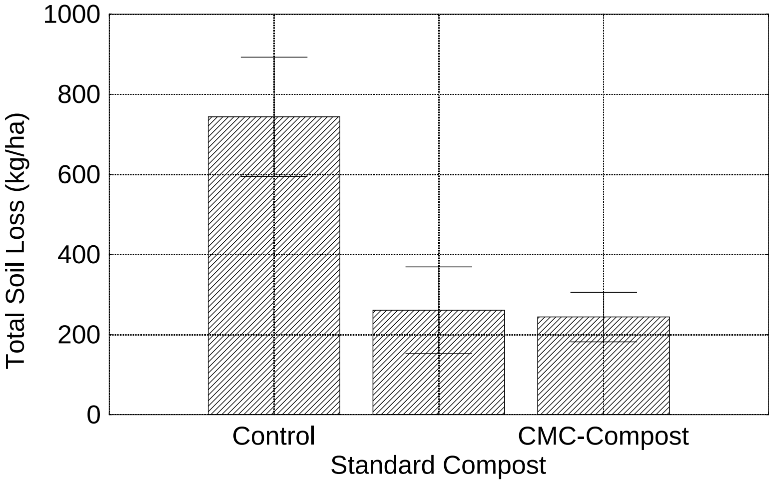

Fig. 2. Total soil loss (kg/ha) of the investigated treatments. Additional bars indicate standard deviation

As seen from Fig. 2, total soil losses of the treatments with compost application reduced to about 1/3 compared to the control treatment without compost. A different behaviour within the compost treatments was not detectable though. Total runoff decreased from 25 mm (standard) to 18 mm (conventional compost) and 12 mm (CMC compost). These differences were significant. It has to be stated though, that due to the limited number of replicates, and the high variation expected for such kind of studies, results should be considered preliminary.

In a follow-up study which is planned for the end of the field experiment, another set of rainfall simulation experiments with a higher number of replicates will be carried out therefore. Fig. 3 plots the relationship between runoff rates and soil loss rates for the different treatments. With increasing runoff rates the amount of soil which is transported increases for all treatments in a slightly exponential form. For each treatment a different shape of the soil loss-runoff relationship may be identified.

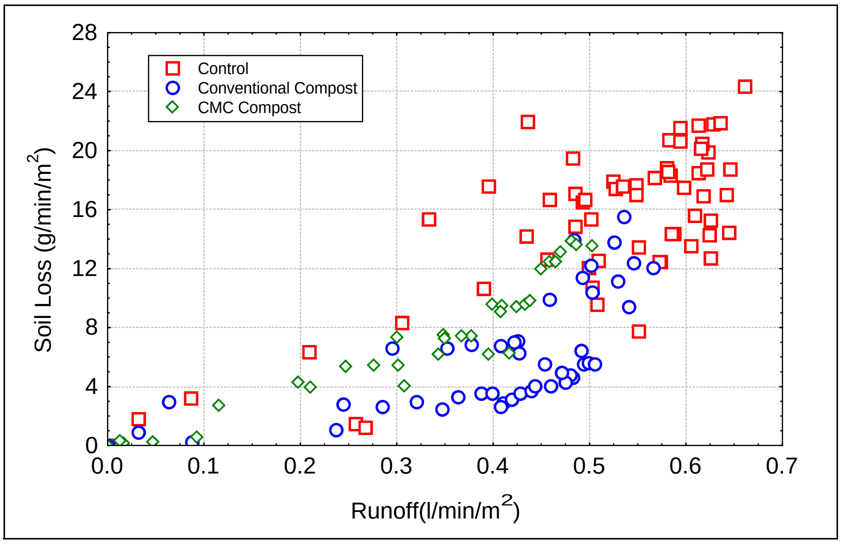

Fig. 3. Relationship runoff – soil loss for the investigated treatments

Compared to the composted plots the control treatment is characterised by a lot of dots in the area of higher runoff rates. This means that on the control plots runoff started earlier and the runoff rates were higher. Reasons for the huge differences in total soil loss are therefore partly due to a different erodibility of the treatments but most of all a result of a different hydrological response of the plots which did not receive compost. Mean values for bulk density, saturated hydraulic conductivity and organic carbon content of the investigated treatments are given in Table 3. Results suggest soil structural improvement as indicated with higher saturated hydraulic conductivities and lower bulk densities of the treatments with compost application. Differences were statistically insignificant, though (p = 0.05).

Table 3. Mean plot values for bulk density, saturated hydraulic conductivity and organic carbon

Treatment	**bulk density** (g/cm^3)	**organic carbon** (%)	**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

Bulk density and saturated hydraulic conductivity both were related to the mean soil loss rates at steady runoff conditions (Fig. 4). Although the relationships between these variables are not very close, again a tendency of lower hydraulic conductivity and higher bulk density values with increasing mean soil loss rates can be observed (indicated with additional lines in Fig. 4).

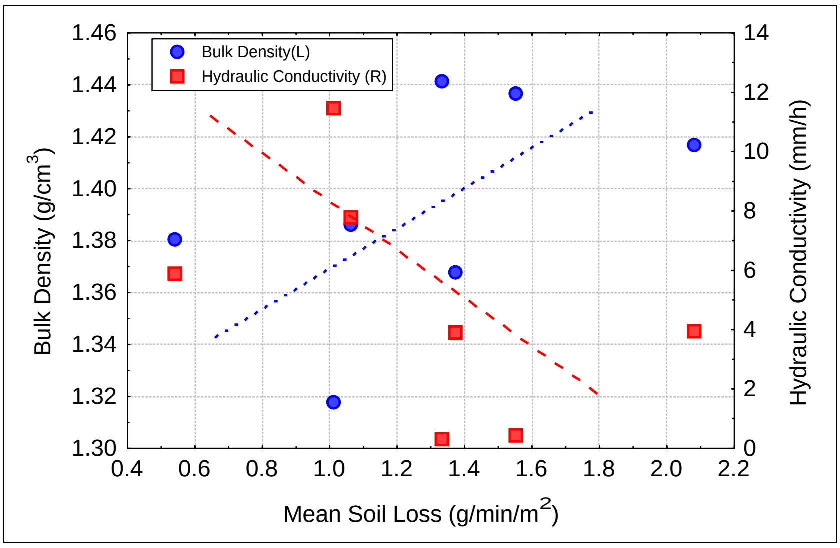

Fig. 4. Mean soil loss at constant runoff rates compared to bulk density and saturated hydraulic conductivity of the plots

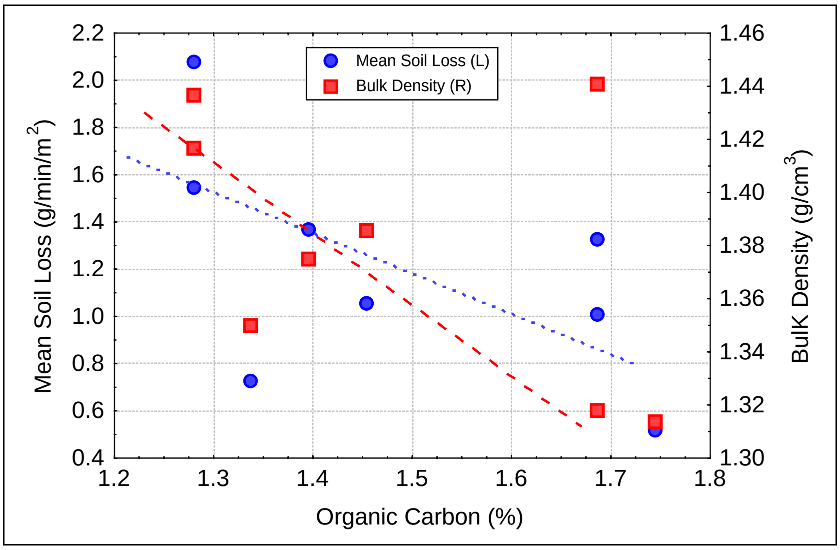

Fig. 5. Organic carbon contents compared to mean soil loss at constant runoff rates and bulk density of the plots

Fig. 5 demonstrates the effect of organic carbon content on mean soil loss rates at constant runoff and bulk density. With increasing content of organic carbon both parameters generally decrease as already reported elsewhere (Adams, 1973; Morgan, 1995). As for Fig. 4, this is indicated with additional lines. Compared to the results given by Körschens (2002) Fig. 5 exhibits a much stronger relationship between bulk densities and organic carbon contents. Due to the fact, that samples for this experiment had been taken from a freshly prepared plot which had received only one rainfall these results certainly do not reflect static conditions but probably more demonstrate the ability of organic matter to slow down soil settling at rainfall.

Compared to the differences in organic carbon content, the reduction in total soil loss of the composted treatments is remarkably high. The different parameter values for bulk density and organic carbon content suggest much lower differences for total soil losses of the rainfall simulation study. Application of the USLE (Wischmeier, 1978) for this experiment for instance would predict a soil loss reduction of about 10 % for the plots with compost treatment. The measured soil properties alone therefore are obviously not able to predict changes in the soil-water system similar to the integrated response obtained via rainfall simulation.

Acknowledgements

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SEVERAL YEARS APPLICATION OF COMPOST - EFFECTS ON PHYSICAL AND MICROBIOLOGICAL PROPERTIES OF SOILS

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Introduction

Bio composts play an important role in German agriculture meanwhile. For instance a third of the produced composts of annually 3 million t are used in crop farming. Needs for information still exist to more precisely judge the useful effects and also the possible risks of compost application. In addition a network research project of the German Federal Environmental Foundation runs for three years. Aim of the project is to concretely work the conditions for a sustainable compost application in the agriculture, to calculate the possible economic benefits globally and to arrange a marketing concept for the economic relations of compost manufacturer and farmer. For this purpose the partners of the network research project can go back to a solid base of six compost field experiments of several years, which are carried out in the Land of the Federal Republic Baden-Wuerttemberg (South-West Germany). Furthermore, an important concern of these experiments is to concretely understand the soil-improving effects of composts. In this contribution we report on first results.

Material and methods

Parameters	Method
• **Soil structure**	
➢ Stability of soil aggregates	Percolation rate
➢ Pore distribution	Water content at diff. suction power
➢ Bulk density	Dry weight of undisturbed soil volume
• **Water regime**	
➢ Water capacity	Water absorption of undisturbed soil
➢ Water infiltration	Infiltration rate (in situ)
➢ Water content	Water content of undisturbed soil
• **Soil microbiology:**	
➢ Biomass	Substrate induced respiration
➢ CO_2-activity	CO_2-production
➢ Enzyme activities	Dehydrogenase activity

Fig. 1. Analytical program

The six field tests are carried out on agricultural farms on typical field locations. For the field test sites soil types were selected, which are expected to have a compost effect: one experiment runs on a very light soil (loamy sand) with humus demand, five experiments on middle soils (silty loams) with suboptimal soil conditions (e.g. problems with the soil structure and the water regime). Four experiments are already in the seventh year, two experiments in the fourth year. Each experiment is locally conducted by a so-called Tandem Team, consisting of a compost company, which supplies the compost, and a farmer, on whose field the experiment is carried out. Thus a very practical treatment of the project is ensured.

Every experiment is carried out according to a uniform experimental design and with uniform crop rotation (corn/ winter-wheat/ winter-barley). Thus a good comparability of the different composts and locations is ensured - an essential criterion for the transferability of the project results on practice conditions. The annual compost dosage is scaled in four levels (K0 - without compost, K1, K2 and K3 - 5, 10 and 20 t/ha dry matter respectively). For simulating under real conditions each com-post level is overlaid by three fertilization levels of mineral Nitrogen(N): N0 - without N, N1 and N2 - each with 50 and 100 % of the optimum (see Timmermann et al, 1999).

The soil-physical parameters and modifications of soil microbiology, which can characterize changes of soil properties by compost application, are regularly examined (see Fig. 1).

Results

The several years experiments have shown that the so-called soil improving effects of the compost application develop little by little. In contrast to the fertilization effect of the composts, which can be found with phosphorus, potassium and lime after few years, compost dosage change soil-physical and -microbiological parameters only on a medium and long term scale. Therefore, due to the duration of the field tests of 4 - 6 years, subsequently only trends are indicated, which can be counted upon in all likelihood when complying with agricultural optimal compost dosage of annually maximum 10 t/ha dry matter.

Parameters of **soil structure** are influenced relatively efficient and also noticeably positive by regular compost dosage. Thus the percolation stability of soil crumbs *(aggregate stability)* particularly on middle soils with higher clay content increased predominantly in the experiments (see Fig. 2).

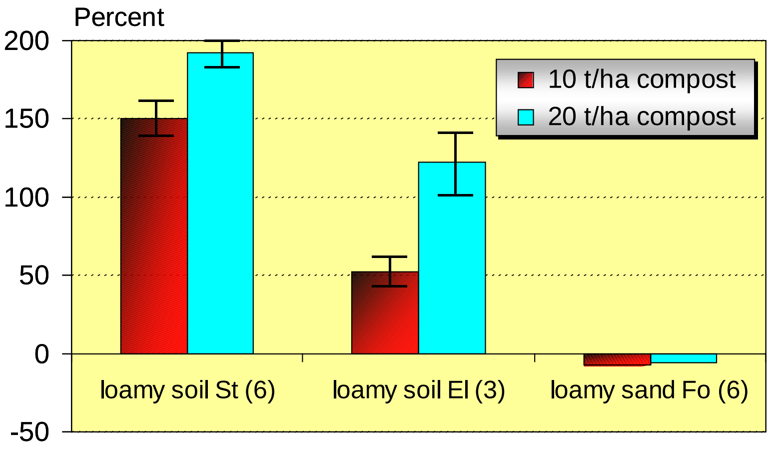


Fig. 2. Effect of compost on aggregate stability - Relative increase in relation to control without compost (= 100 %) results of year 2000

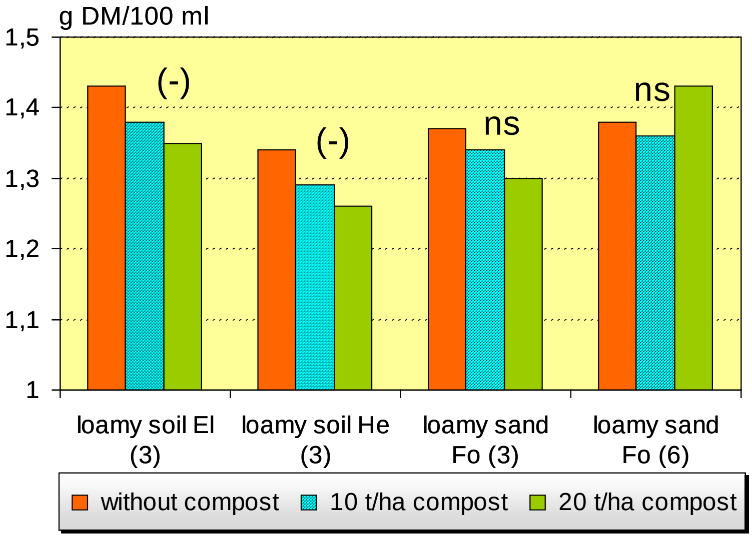


Fig. 3. Effect of compost on bulk density – Results abs. in g soil (DM)/100 ml soil – Locations El, He and Fo, years (3) and (6), n.s. – not significant, (-) – tendency to decrease

Therefore the soil becomes more elastic and easier to run over. Furthermore, on areas of arable land with slope inclination the erosion hazard is clearly reduced. The *bulk density* of the soil usually decreases by supply of organic matter (see Fig. 3), consequence of which is a better drainage as well as aeration. The positive effects of compost on the **water regime** of soils are remarkable. The *water capacity* was sustainable promoted in some cases (see Fig. 4). The improved water binding contributes to a prevention or reduction of crop yield loss on dryness, particularly on light sandy soils. In consequence of the increased water capacity soils treated with com-post usually show higher current *water contents, too* (see Fig. 5).

That affects the water supply of the plant positively. Also the *water infiltration* of the soil can be improved by compost. This effect, which predominantly plays a role on soils with higher clay contents, effects a better water conductivity of the soil. Thereby, particularly after heavy rainfall the soil dries faster. This can affect the running over of areas of arable land favourably.

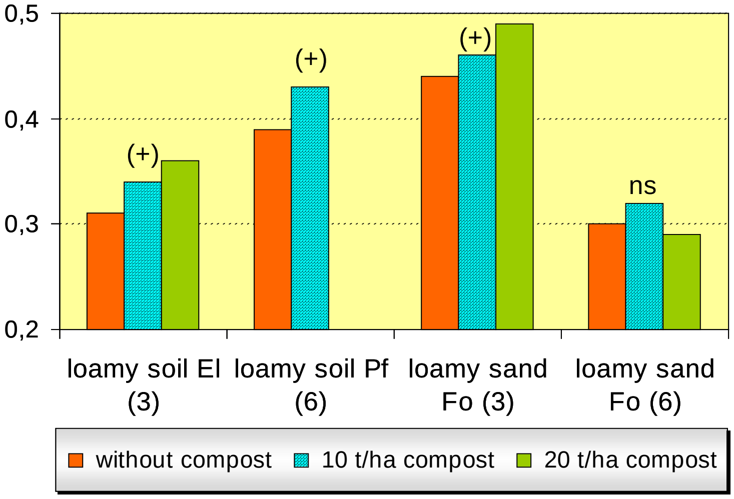


Fig. 4. Effect of compost on water capacity – Results abs. in g water / g soil (DM), Explanation contractions see Fig. 3

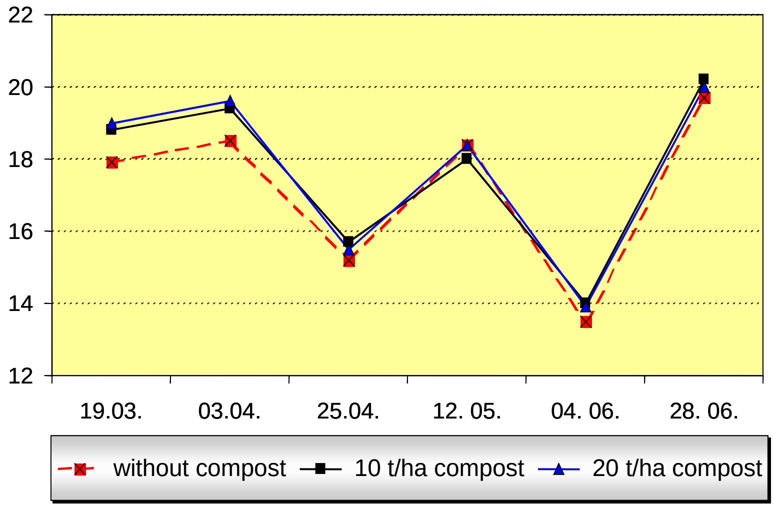


Fig. 5. Effect of compost on water content – Results abs. in % FM in vegetation period – loamy soil St

Compost applications have a promoting effect on soil life and particularly **soil microbiology**. Along with the content of organic matter of soil the *microbiological biomass* in soil usually in-creases. A rise in microbiological easily utilizable carbon in soils *(denitrification potential)* in con-sequence of the compost fertilization is detectable. The outcome of this is an increase of the microbiological biomass and a significant increase of the biological activities *(CO_2-activity)* in soil. The microbiological metabolic performances (*Dehydrogenase activity*, see Fig. 6) and so that the mineralization rises clearly. The supply of plants with nutrients is improved. Above all the initially widely bound nitrogen becomes increasingly plant available with the years. Besides, so-called soil improving effects are expected. Apart from a promotion of the microbiological supported soil functions (transformer for nutrients and pollutants, nutrient buffer etc.), further indirect effects, like the improvement of the soil hygiene and the promotion of the soil fauna, is conceivable.

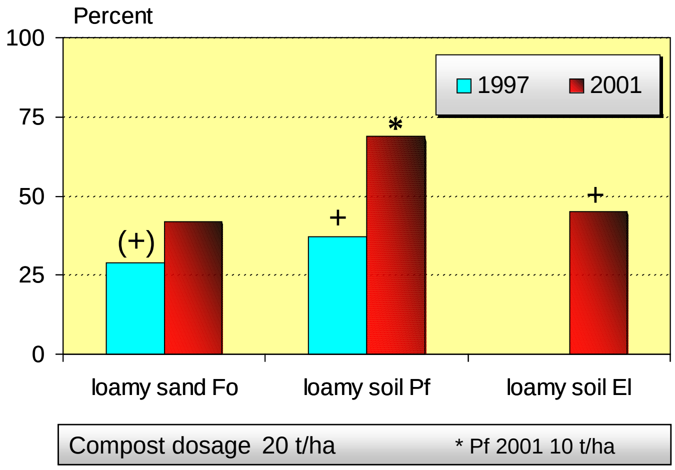
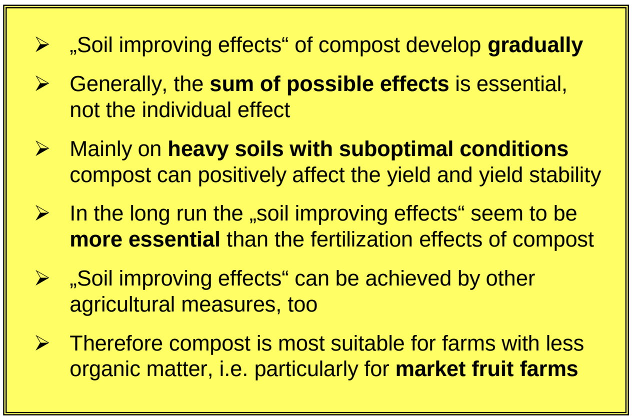


Fig. 6. Effect of compost on dehydrogenase activity – Rel. increase in relation to control without compost. Locations El, Fo and Pf (+) - Tendency to increase, + - significant increase



- „Soil improving effects" of compost develop **gradually**
- Generally, the **sum of possible effects** is essential, not the individual effect
- Mainly on **heavy soils with suboptimal conditions** compost can positively affect the yield and yield stability
- In the long run the „soil improving effects" seem to be **more essential** than the fertilization effects of compost
- „Soil improving effects" can be achieved by other agricultural measures, too
- Therefore compost is most suitable for farms with less organic matter, i.e. particularly for **market fruit farms**

Fig. 7. conclusions

Conclusions

After the results of the relatively short experimental period the impression concentrates that the importance of the application of composts beside fertilization effects is prior to the sum of possible so-called soil improving effects, which develop little by little (see Fig. 7). Particularly, on middle to heavy soils with insufficient structure, soil compactions, poor aeration and insufficient soil activity definite improvements can be obtained by regular application of composts, which positively affect the yield and yield stability. Under advantageous conditions the productive efficiency of the location can even be raised to an extent that a clearly higher yield level is achieved. It is out of question that such effects can also be achieved by other agricultural measures, like regular green manure, straw fertilization and use of farm manure. Therefore compost is particularly the suitable means for pure market fruit farms without livestock owning, where the soil in many cases is not sufficiently supplied with organic matter.

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EFFECT OF LONG-TERM COMPOST APPLICATION ON PHYSICAL PROPERTIES OF LOAMY SOILS

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Introduction

The benefit of a compost application not only derives from its nutrient effect, also very important is the effect of the supplied organic matter on pedobiological, especially pedophysical characteristics. The change in the pedophysical properties generally results from the cumulated effect of substantial amounts of humus, accumulated over a longer time period. Normally, the soil-improvement effects are more pronounced on sandy soils than on loam soils. However, the latter frequently exhibit problems as regards soil structure and erosion liability. In two field trials, the influence of compost application on pore volume, pore-size distribution and aggregate stability of fertile loess-loam soils was specifically studied (Lamp, 1996).

Material and Methods

The two compost trials (Table 1) were conducted on brown earth soils, that have developed on loess layers over sandy or sandy-clay tertiary material. The soils vary in their texture, pH value and humus content. In both trials, compost application increased the pH value, as well as C and N contents. (Table 2). Differences in texture within a specific trial were small, so that a significant influence of this factor on the trial results can be excluded.

Table 1. Description of the field trials

Trial I:		
Trial period:	3 years	
Treatments:	without compost	
	with compost:	84 t DM biowaste compost in 2 applications
Trial II:		
Trial period:	22 years	
Treatments:	without compost	
	1 x compost:	approx. 52 t DM waste compost / biowaste compost every 3 years
	2 x compost:	approx. 104 t TS waste compost / biowaste compost every 3 years

After a trial period of 3 and 22 years respectively, soil samples were taken in spring from a depth of 5 – 15 cm. Pore volume and pore-size distribution were determined by measuring the water content of sampled soil cores in equilibrium with a defined water tension, acc. to Hartge (1965). The aggregate stability was determined by percolation method, according to Becher and Kainz (1983); i.e. the amount of water that percolates in 10 min through a package of air-dry aggregates (diameter 1 – 2 mm) at a hydrostatic pressure of 20 cm water column is measured. The percolation rate is reduced with progressing aggregate decline.

Table 2. Characterization of the soils of the field trials (topsoil: 5-15 cm)

	clay	silt	sand	pH	C	N_t
		%			%	
			trial I			
without compost	16	46	38	5.6	1.36	0.17
with compost	17	46	37	6.0	1.86	0.21
			trial II			
without compost	27	53	20	5.7	1.00	0.11
1 x compost	25	48	27	6.9	1.93	0.21
2 x compost	23	51	26	7.0	2.38	0.25

Results

Pore volume and pore size distribution

The total pore volume increased in both trials with the progressing accumulation of organic matter by compost application (Fig. 1). This was mainly due to an increase of the wide coarse pores (equivalent diameter > 50 µm). A slight increase was also observed for the narrow coarse pores (10 – 50 µm). Under consideration of the natural variability of analysis data, the share of medium pores (0.2 – 10 µm), and thus the capacity to hold plant available water, remained unchanged, as well as the share of fine pores (< 0.2 µm).

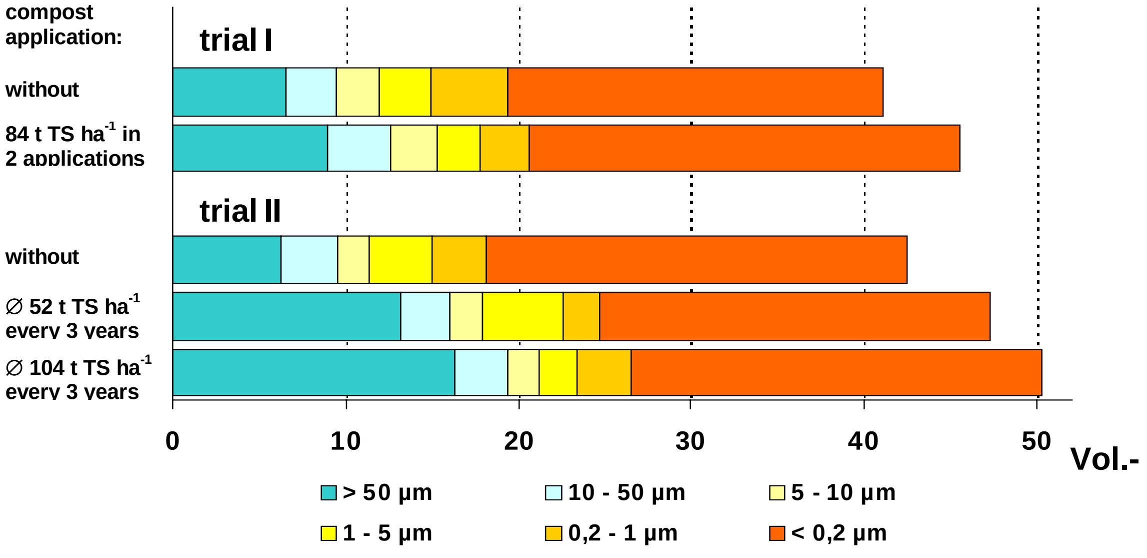

Fig. 1. Effect of compost on pore size distribution of topsoils (5-15 cm)

Aggregate stability

Due to the different texture of the trial soils, the percolation stability of the aggregates was significantly higher in trial 1 (higher sand fraction) than in trial II (Table 3, 'without compost'). Independently of this fact, compost application led in both trials to an increase in aggregate stability (higher percolation rate). Thus, a similar trend was observed as for the soil C content. Similar to the absolute percolation level, the increase in the amount of percolate, compared to the respective control ('without compost'), was higher in Trial I than in Trial II. However, relative to the control soil, it was significantly lower in Trial I (167 %) than after long-years compost application in Trial II (231 and 247 %, resp.).

Table 3. Percolation stability of aggregates in topsoil (5-15 cm). Values in brackets: Standard deviation

	percolation rate
	ml 10 min^{-1}
trial I	
without compost	51.5 (± 2.7)
with compost	86.0 (± 4.8)
trial II	
without compost	15.4 (± 2.9)
1 x compost	35.6 (± 2.5)
2 x compost	38.0 (± 0.3)

Discussion

The present study shows that compost application on loam soils especially increases the volume of wide coarse pores (equivalent diameter > 50 µm). This is confirmed by several other studies (Buchmann, 1973; Giusquiani et al., 1995; Asche et al., 1995). For the narrow coarse pores (10 – 50 µm) and medium pores (0,2 – 10 µm), an increase, as described by Asche et al. (1995) for loess para-brown-earths, could not be found, or was observed only as a trend (narrow coarse pores). In any case, for the fertility of the loess-borne soils studied here, an increase in their water holding capacity or their available field capacity is of lesser importance. Here, the problems originate predominantly from insufficient aeration (prone to pseudogley formation) and in their liability to erosion. Thus, the increase of quick-draining pores with an equivalent diameter of > 50 µm, that are important both for air exchange and water infiltration, is a major contribution to the improvement of these soils.

The cause for the formation of coarse pores is probably the increased soil-fauna activity in the soils to which compost had been applied. This is further corroborated by the raised water conductivity found in these trials (Ebertseder, 1997), which indicates a high degree of continuity among the formed coarse pores. Also the observation, that macropores formed in soils after compost application are to a large degree lined with organic matter (Giusquiani et al., 1995), indicates the more active soil fauna as the possible cause.

The observed increase in percolation stability may be mainly due to a coating of aggregates with organic matter after substantial compost application. Primary cause for the decline of aggregates is the rising pressure from the air enclosed in the aggregates, that results from the water which enters the aggregate pores from all sides (Auerswald, 1995). The organic coating reduces the wettability of the aggregates by the water (Zhang and Hartge, 1992). The water enters more slowly, so that the pressure within the aggregates builds up more slowly and to a lesser degree. This applies not only to the original organically-coated macroaggregates, but also to their fragments (Zhang and Hartge, 1992; Auerswald, 1995).

As the results show, percolation stability increases with progressing humus accumulation in the soil. This was also confirmed by trials with farm-yard manure and crop residues (Becher, 1996) and studies with a large variety of soils (Auerswald, 1995). Additionally, the lime supplied with compost may also have contributed to the higher aggregate stability (Becher and Schwertmann, 1973; Kiener, 1987), at least in trial II (pH » 7).

Percolation stability is closely related to the soil's liability to erosion (Kainz and Weiß, 1988). Therefore, it can be assumed that the use of compost can contribute to the prevention of topsoil losses. Besides the long-term rise in aggregate stability by humus accumulation, the more rapid water infiltration as result of the changed pore system also strengthens this effect.

Summary

In trials over several years (3 and 22 years resp.) on loess-loam soils, compost application resulted in an increase of the humus content, connected with more macropores and raised aggregate stability. It can be thus assumed, that the application of compost improves soil aeration and water infiltration, and reduces erosion liability.

All in all, the results show that compost application, even on good arable sites (loess soils), contributes to improve physical soil characteristics, and thus promotes the sustained use of these soils.

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USING COMPOST IN PRODUCTS FOR HORTICULTURE AND LANDSCAPING

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Demand

In Germany this topic represents an important field, firstly with regard to a very positive demand for products based on compost for commercial, landscape and hobby gardening. This results in a great product diversification like potting soils, container planting soils, nursery soils, planting and gardening soils, vegetation layers and substitute of topsoil.

Secondly it represents an important field with regard to mass potential. There are about 50-80 composting plants with soil mixing facilities in Germany. Actually 10 - 20% of compost is already used for the production of soils and potting media.

Thirdly higher prices can be realized (compost: 2,5-10 € / m^3, substrates: 20-80 € / m^3) if compost is used this way than for agriculture.

Resources

This situation does not only concern northern EC-countries with regard to the pushed peat substitution but to the same extend we noticed a strong interest in southern EC-member states. Mainly in Spain and Portugal but also in Greece and Italy, where peat does not exist and other raw materials for substrates are rare, this leads to a considerable import of peat-based materials with all the negative ecological effects of long-distance transport and rapid peat exploitation.

It would be much more reasonable to use own organic resources by composting and utilisation of compost products, but the potential is still rarely used. This applies in general and particularly to the production of compost-based soils and substrates. Thus, high amounts of organic matter as essential resource are buried in dumps where they cause other problems.

Application

Experts in Germany expect a potential of roughly about 2 mio. m^3 of quality tested compost per year in soils and media (800.000 m^3 in potting media for commercial and hobby gardening, 1,2 mio. m^3 in planting and gardening soils / vegetation layers for hobby and landscape gardening).

In accordance with the requirements of the plants at least 30 vol.% and up to 80 vol.% of high quality compost (e.g. low in nutrients, soluble salts and heavy metals) can be incorporated in the mixture.

The range of application offers many possibilities, it depends if fertilizing effects, soil amelioration effects, suitability for potting media or special characteristics like suppressiveness towards soil borne plant pathogens are wanted.

The examples we presented here show why we think this is an area of application with increasing importance in Europe.

COMPOST QUALITY AND UTILIZATION

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Abstract

Long-term experiences have clearly demonstrated that only high quality compost can be utilized in agriculture as an organic fertilizer. Demand for quality compost is rather high in Europe, particularly in Mediterranean area where organic matter content in agricultural soils can be very low, near to desertification. In spite of this high need in soil organic matter, a huge amount of poor quality compost is still produced in these regions. The main reasons for the production of a low quality compost are: (1), composition of the starting material; (2), composting system and control of the process. As far as starting material is concerned, a considerable work has been done to define quality parameters; besides, source separation of municipal solid waste has greatly contributed to collect a clean organic matter for composting. On the contrary much less has been done to improve compost systems and process control. To day plants without any logic process still exist generating a product which fate normally is the landfill. Effort should be done at European level in order to implement also this sector of primary importance. Training courses, teaching advanced technologies for plant and process control, could educate people working in this field. Also a closer collaboration among different operators in this sector (politicians, administrators, scientists, industrials, compost utilizers) will result in a positive improvement of compost technology.

Legal Framework for Compost Application in Europe

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Introduction

Nearly all of the European countries started to compost or digest their separately collected organic wastes from gardens, households and parks, partly also from industrial areas. Countries with more advanced experiences in composting had the recycling aspect as their basic idea, contrary to the countries which are now in the beginnings of a biological waste treatment, for them the European guidelines for landfills with the prohibition of a large-scale landfilling of organic material are relevant. Despite of the different aspects, the main idea still is to bring back the recycling product successfully into the material loop and to find an application for it and a sales market. The intersecting point from the recycled material of the waste industry to the end product is especially interesting. The influences of the product properties coming from the waste properties on application and possible sales are essential.

The product properties and thus a successful use can only be realized if the recycling product stipulates the minimum criteria and legal regulations of the product quality and product application.

In this connection the different conceptions and ideas of the individual European countries are presented. The range reaches here from the stipulation of admitted raw materials for the compost process over defined quality requirements, especially considering heavy metals, to legal directions for fertilisers.

Basic aspects of the European development

The regulations and standards for compost use are extremely varying among the member states. There are countries where compost use is included in a dense net of different regulations, (Germany, Austria) and then there are countries where compost can be used without any legal directions. These differences are partly subject to the history of these countries and partly depend on the developing steps of the biological waste treatment. Countries like Germany and Austria are famous for the multitude of standards. Together with a more than 10 years tradition in composting this lead to the fact that the experiences gained in these countries were collected in a compost ordinance.

Countries which start with an establishment of organic waste recycling concentrate in a first phase on separate collection and composting processes. Legal regulations are usually set up for harmful ingredients of the compost, whereby limit values for heavy metals are very typical.

Here the limit values are often deduced from the range of sewage sludge because of a lack of thorough examinations. The US has undertaken a risk assessment about harmful material getting in plant edibles on their way from the compost into the soil and from there into the plants or via the productive livestock in animal foodstuff. This leads to a higher limit value by the factor 1000.

The nutrient factor is usually tackled not before it is clear which qualities are produced in the country and when considerable quantities are available for a plant. Or the existing regulations for fertilisers resp. the guidelines for nitrate and phosphate in the EU are relevant.

More or less it is advantageous that the responsible authorities for soil conservation, for the fertiliser law and the law of water protection in few EU Countries have not yet discovered the biocompost. (South Europe, Sweden, Finland).

Framework by laws

Various laws influence composting and compost application in the European countries e.g.

- Waste Law
- Fertiliser Law
- Soil protection laws
- Sewage sludge ordinance
- Law of water protection
- Epizootic Disease Act
- Animal Carcass Disposal Act

The first three are the most important.

Waste Law

In the waste laws precautionary measures come into the foreground like mentioned in the Finnish waste law: Compost used as fertiliser or soil improver may not contain harmful substances or microbes in such amounts that its normal use can cause hazard to people, plants, animals or environment. Requirements in the European laws are laid down for heavy metals, organic pollutants, sanitation, application ranges and impurities like glass, stones, plastic.

The levels in Europe differ very much, even between countries with a large compost production. Some regulations lost the relation to the practice. E.g. it is obvious in the Netherlands, that normally no composting plant working on an industrial level with biowaste is able to produce compost with 75 mg/kg din zinc. The neighbour Germany might be able to reach 300 mg/kg as experience with several million tons of compost during the last years show.

Table 1. Heavy metal requirements for compost

Heavy metal concentration (mg/kg dm)	**Maximum concentration Finland**	**For max. 20 t of biowastes in 3 years Germany**	**'Very good Compost" Quality Netherlands**	**Maximum concentration Denmark**
Chromium	-	100	50	100
Mercury	2	1	0,2	0,8
Cadmium	3	1,5	0,7	**0,4**
Arsenic	50	-	5	25
Nickel	100	50	10	30
Lead	150	150	65	60
Copper	600	100	25	1000
Zinc	1.500	400	**75**	4000

The efforts of the Danish EPA to open a market for household waste compost by fixing very low limits for Cadmium and organic pollutants (DEHP) might work contradictory. As first analysing results show most of the household and garden waste composts reach or exceed these limits. A product which normally doesn't fulfil the standards has no chance to build a positive image as a high quality recycling product.

Table 2. Cadmium and organic pollutants (DEHP) in Danish compost with different parts of organic household waste

% of household waste in relation to garden waste in raw material	Cadmium in compost (mg/kg dm) (Limit value = 0,4)	DEHP in compost (mg/kg dm) (Limit value = 50)
85-100	0,27	**60**
70-80	**0,40**	31
40-60	**0,50**	4,8
10-30	**0,40**	0,55
0	**0,47**	0,55

It is very important that the fertiliser law is co-ordinated with the precautionary measures in the waste law. Exemplary is the Biowaste Ordinance and the Fertiliser Ordinance of Germany. The Biowaste Ordinance regulates the waste aspects and the Fertiliser Ordinance the part of nutrients and both of them refer to each other.

Fertiliser law

It must be principally noted that today's good compost qualities in Europe when applied, effect the nutrient restrictions before the limit values for heavy metals.

Table 3. Fertilising limitation for compost

Nutrient spreading limitations	Nitrogen in kg/ha	Phophorous in kg/ha
Denmark	170	30
Netherlands	-	35 -80
Sweden	150	22-35

Denmark shows a typical example for nutrient and load restrictions for fertilising. The **total supply of nutrients** in the form of waste products must not exceed **210 kg of total nitrogen** (170 kg N after 2002 because of the EU Nitrate directive) and **30 kg of total phosphorus/ha/year**. The phosphorus quantity can, however, be calculated as a three years' average. Compost applied on agricultural or other areas constitutes part of the permissible total fertiliser volume and may be **spread in quantities** up to **7 t/ha/year** (dry matter, calculated as a 10 year average). In parks and woods where no foodstuffs are cultivated it is permitted to use up to **15 t/ha/year** (dry matter, calculated as a 10 year average) organic fertiliser.

Table 4. Load restriction for compost

Load limitations in t/ha dm	Area for food production	Non food production area
Denmark	7 t/ha/year - 10 years average	15 t/ha/year - 10 years average
Netherlands	6 t/ha/year - (12 t/ha two years)	3 t/ha/year - (6 t/ha two years)
Austria	8 t/ha/year - 5 years average	40 t/ha in 3 years /400 t in 10 years

In the Netherlands the pollution of soil and groundwater with nitrogen and phosphorus is a very big problem. In this context the strict load restriction of e.g. 6 t per ha and two years are understandable, despite the fact that the spreading of such low amounts of compost create problems.

In order to fulfil the EU Nitrate directive from 2001 all livestock producers with more than 0.5 Livestock Units per ha and all arable farmers and other open-field producers are connected to the Minerals Accounting System (MINAS), which should lead to a balanced application of organic and inorganic manure and fertilisers which include compost. Registration of phosphate and nitrogen flows on a farm which are to be reported to the competent authorities annually.

Mineral inputs and outputs should be in balance although a certain loss is allowed. With respect to MINAS compost application is allowed as long as the nitrogen and phosphate balance is given but with the above mentioned restrictions.

Soil protection law

A preventive regulation is also soil protection. Fortunately realistic attitudes of the soil protectors are to be recognised e.g. in Germany. Former soil protection demands required an improvement of the soil quality with the application of compost. Nowadays it is accepted the this is impossible and that the use of compost worsens the soil to a certain extend. With the new soil protection law in Germany a certain deterioration of the soil is possible as long as it doesn't create a harmful change of the soil or inconveniences for the public. For soil protection reasons the application of biowaste or mixtures is prohibited in several countries if the heavy metal concentration in the soil according to table 5 is exceeded:

Table 5. Limit values for max. Permissible concentrations of heavy metals in soil

Heavy metals (mg/kg dm)	**All soil types Denmark**	**Soil type clay Germany**	**Soil type loam Germany**	**Soil type sand Germany**
Cadmium	0,5	1,5	1	0,4
Mercury	0,5	1	0,5	0,1
Lead	40	100	70	40
Nickel	15	70	50	15
Chromium	30	100	60	30
Zinc	100	200	150	60
Copper	40	60	40	20

The compost quality standard in the Netherlands refers to the soil protection law. The regulations of this law are adapted in the new version of the assessment guidelines for compost and include the governmental decision to reduce load of soils with heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn, As). The new strategy from the year 2000 on **is that the supply with heavy metals should not exceed the removal.**

Input regulations

The selection of the raw material influences the later application considerably. That must not result from a different compound of nutrients from different raw materials. The typical raw material makes the compost suitable or not suitable for application in the eyes of the user. A compost with components from green waste has another weight as compost from mixtures of sewage sludges.

Visual properties which are influenced by the raw materials both on the side of the nutrients and the side of harmful matter are relevant, too. Some of the European countries admit only a certain amount of groups of raw material for composting (biowaste, green waste, animal waste from agriculture, sewage sludge) or they develop lists - mostly as positive lists - which material is admitted or prohibited for composting. Typical raw material groups in Europe suitable for composting are:

- Organic waste from households
- Park and garden waste
- Food waste from large kitchens and restaurants
- Industrial organic waste
- Animal residues even from slaughterhouses (e.g. Sweden)
- Municipal solid waste after removal of harmful contaminants (e.g. Austria)
- Compost additives

A special field are areas with geogenic preloads. An enrichment of the composts with usually one heavy metal (e.g. copper) through the soil contents are surpassing the stipulated standards and limit values. In the areas where this is the case the compost plants have usually a higher duty of care in so far as they must guarantee that those composts are only applied in the same region.

Potential dangerous substances might be excluded e.g. potato residues and phosphate carrier in the Netherlands.

Process regulations

Process regulations, when it comes to application, concern in most countries the hygiene and especially the phytohygiene. Tile end product must be free of weeds and germinable plant parts.

The more important points are the requirements for the internal analysis. The analysis done in the framework of quality assurance systems are only spot checks. The producer of compost must guarantee product properties for every gram of compost which is sold. So a continuous internal analysis of product parameter has to be done which is in addition the basis for an extensive declaration.

Product related regulations

Product related properties and regulations can affect the compost application. In several European countries garden waste compost (Denmark, Netherlands) is automatically seen as a high quality product and therefore - contrary to biowaste compost - nearly free of application restrictions.

The decomposition degree (e.g. fresh and mature compost (Germany, Austria)) or the defined purpose of use (mulch and substrate compost) of the produced compost types influences the application quite well, too.

In order to manage compost application properly a strong demand for an extensive declaration of the product properties can be detected in several European countries (Germany, Denmark, and Sweden). As a requirement by the compost plants and the users the declaration should include extensive application recommendations.

Application related framework

Above the fertilising regulations very detailed recommendations and information are required when it comes to special products e.g. compost in roof greening mixtures. In most of the EU countries the user groups have developed norms for that special types of compost application which have to be considered.

Differing demands for the compost product exist when it is applied in e.g. ecological farming (Austria) or on land for food production and non food production. In the latter case the requirements for the product quality are lower and higher amounts of compost can be applied (Denmark, Sweden).

Summary

The legal framework differs very much in the European Countries, which is mostly based on the development in the Country when it comes to the recycling of the organic residues from households, parks and gardens. On account of environmental protection and precaution reasons biological treatment needs a certain extent of statutory regulations e.g. for heavy metals or for hygiene requirements. The extent of Germany and Austria with their 50 pages of Biowaste ordinances and another 100 pages of explanations to the ordinances are not examples which should be copied by other countries. If, in the long run, compost wants to be successful on the market, it has to be established like a product and it has to fulfil the requirements of the users. Voluntary standards in the frame of quality assurance systems (like in Germany, Belgium/Flanders or Austria) are much more flexible which makes it easier to develop compost based products which can be applied successfully.

Panel forum and open floor

Organic Matter Management & Sustainability – Do We Need Compost?

This session was presented as a panel forum and open discussion. Members of the panel were:

Participant	Sector or responsibility
Luca **Marmo**	*Chair ;* EU Commission, Directorate-General Environment
Antonio **DE ANGELIS**	EU Commission, Directorate-General Agriculture
Herman **VAN BOXEM**	EU Commission, Directorate-General Environment
Elise **BOURMEAU**	European Federation of Waste Professionals (FEAD) and WG4 Biological Treatment Regulation on Composted Sludge, Animal By-Products and Soil Protection (F)
Morten **BRØGGER**	ISWA working group on biological waste management; SOLUM, Private Society, involved in an association work group on solid wastes and various uses of composts (DK)
Thomas **DELSCHEN**	State Environment Agency – North Rhine-Westphalia (D).
Ward **DEVLIEGHER**	VLACO, Flemish Compost Association, representing governmental composting plants. Supports composting development, waste prevention, research on compost advantages and quality assurance, (B)
Jane **GILBERT**	Composting Association (UK).
Rainer **LATTEN**	COPA-COGECA, European Farmers Organisation,Consultancy (D)
Karla **SCHACHTNER**	Federal Quality Association of Compost, involved in monitoring of compost (D)

Written statements from some of the panellists are to be found in the following pages. Notes were taken from the open floor discussion by Robin Szmidt and Laure Metzger. It was not possible to record all contributions to the floor but every effort was taken to ensure key points were recorded.

Contributions to the debate are attributed where possible. Unknown comments from the floor are noted as *"Floor"*. The Rapporteurs apologise for inadvertent mistakes in spelling or affiliation.

Written Statements from the Panel

.... Do We Need Compost ?

THOMAS DELSCHEN

Northrhine-Westphalia State Environment Agency, Essen, Germany

A STATEMENT FROM THE VIEWPOINT OF SOIL PROTECTION

The statement from the viewpoint of soil protection can be summarized as follows:

(1) As a contribution to sustainability compost **is needed** as substitute for limited natural resources (e. g. peat, mineral fertilizers).

(2) In agricultural soils application of organic matter by compost amendments **is not needed but useful**, especially in live-stock-less farming systems.

(3) Nevertheless recycling of (produced) plant material **contributes to sustainable agriculture.**

(4) **Benefits** of compost application in agriculture mainly result from its content of organic matter and plant nutrients.

(5) **Risks** raise mainly from the input of pollutants (heavy metals, POP's), overloads of nutrients and accumulation of organic N-fractions.

(6) Accumulation of pollutants in amended soils is not sustainable.

(7) There is need to **balance benefits and risks** of compost amendments to agricultural soils through

   a. application rates according to „good practice of fertilizing“ and
   b. limitations of pollutant inputs.

(8) There are 2 equivalent options to protect amended soils against accumulation of pollutants:

   c. reducing inputs to the output level (considering other not avoidable inputs) **or**
   d. limitation of pollutant concentrations in composts (on ash basis) to the corresponding concentrations of the amended soil

(9) At this time 2nd option seems to be more realistic and attainable in the case of compost.

(10) As a temporary and practicable convention the pollutant concentrations in composts should be limited to precautionary soil values (e. g. precaution values of the German Soil Protection Ordinance).

JANE GILBERT

The composting Association, UK

COMPOSTING IN THE UK

The composting industry in the UK has expanded significantly in recent years and this trend seems set to continue. Whilst large-scale composting of agricultural wastes and forest residues has been practised for many years, much of the expansion in the composting sector has been a result of municipal waste composting. After several years of sustained growth, mainly based on green waste composting, the UK composting industry is at a crucial stage in its development. There is now evidence of increasing diversity in terms of composting processes and wastes utilised, although certain legislative constraints are impeding this at present.

Composting has a pivotal role to play in closing the ‘organic loop’, returning organic matter and valuable plant nutrients to soil. There is much interest at present to use composts within the agricultural and horticultural sectors at present. It has been estimated by the Department of the Environment, Food and Rural Affairs that the organic matter in agricultural soils in England and Wales decreased by 0.49% between 1979 and 1995. This was recognised in the draft soil strategy for England published in March 2001, which set in place a series of recommendations to try to stem this trend. Composts may therefore play a key role in helping to improve soil organic matter in depleted arable land, especially in the East Anglian region of England. However, the recent proposals by Government to implement the EC Nitrates Directive (91/676/EC), which would categorise almost the whole of England as a Nitrate Vulnerable Zone, may well place significant restrictions on application rates.

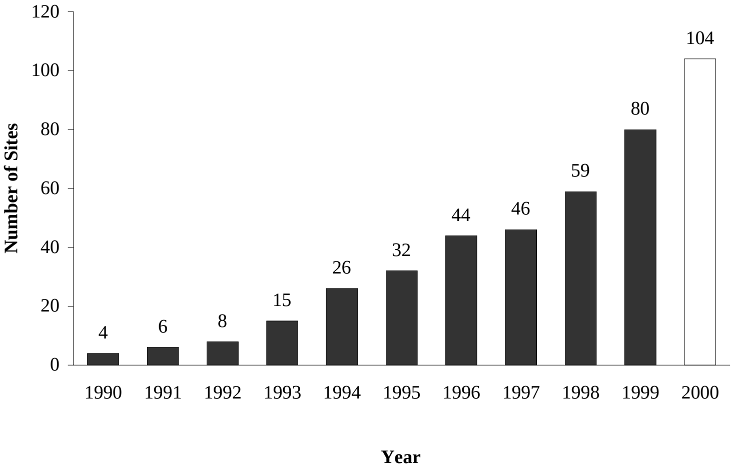
Using composted green wastes to offset the use of peat in horticultural growing media is also receiving considerable attention from environmental groups within the UK. A ten-year programme of work has been planned to source and trial alternatives, aimed at both the retail and professional sectors. Composting is therefore being seen as part of the solution towards implementing more sustainable agricultural and horticultural practices within the UK.

The principal legislative drivers affecting composting to date have been the respective waste strategies in England, Northern Ireland, Scotland and Wales, and the Best Value performance indicators set in England. Central to these is the European Union Directive on the Landfill of Waste (99/31/EC), which came into force in 1999. In addition to stipulating the way in which landfill sites should be operated, it places strict limits on the amount of biodegradable municipal waste that can be disposed of to landfill, and introduces a requirement for pre-treatment of all wastes prior to landfill. The Directive is therefore likely to have a profound effect on the way in which biodegradable wastes will be collected and processed, and will inevitably stimulate the development of the composting sector.

During late 2000 and early 2001 the European Commission published two draft working documents on the Biological Treatment of Biowaste. These were intended to promote discussion between Member States and set the basis for European legislation for the management of biological wastes. The documents proposed a hierarchy that placed composting or anaerobic digestion of separately collected wastes above both mechanical/biological treatment (MBT) and the use of biodegradable waste as a source of generating energy. To promote this hierarchy the documents suggested separate collections for compostable wastes. The latter document also proposed a three grade classification, distinguishing between two grades of 'compost', and a third classification for 'stabilised biowaste'. Further development of the working document appears to be dependent upon the development of a Soil Communication by the European Commission under the 6th Environment Action Programme.

The Composting Association's annual surveys have suggested that composting has developed considerably during the 1990s (Fig. 1) (Slater et al., 2001). Feedstocks, however, have primarily comprised municipal green garden wastes collected at civic amenity sites (54 % of total), which have been processed at open-air turned-windrow facilities, most of which had a throughput of less than 7,000 tonnes per annum. Given the legislative drivers, both collection and processing techniques will need to change in order to accommodate both increasing quantities and a greater diversity of feedstock types.

Fig. 1. Cumulative number of composting facilities in the UK



The development of composting has, however, been significantly curtailed as a consequence of the Foot and Mouth Disease (FMD) epidemic that swept across Britain during the early part of 2001. The hastily drafted Animal By-Products Amendment Orders in England, Scotland and Wales in essence precluded the composting of catering wastes, leading to confusion and frustration across the industry for producers and local authorities alike. In order to address this problem, the Department of the Environment Food and Rural Affairs (DEFRA) has commissioned a comprehensive study assessing the risks of composting catering wastes and animal by-products, which will form the backbone of Government policy in the future.

Commensurate with this has been the development of an EU Regulation Laying Down the Health Rules Concerning Animal By-Products Not Intended for Human Consumption. Concern by some Member States about the potential spread of animal diseases, such as FMD, through composting led to the inclusion of catering wastes from households within the scope of the Regulation. The draft sets out prescriptive collection and processing requirements, which may significantly influence the direction the UK takes.

In addition to all of this, concern by the Environment Agency about the environmental impacts of composting led them to publish a position statement on bioaerosol emissions during mid 2001. They proposed a 250 m cordon sanitaire around composting facilities, which has, again, created significant problems for some operators, many of which have been established for many years and operated without difficulty until now.

As part of its work programme developing standards for composts, the Waste and Resources Action Programme (WRAP) has organised a number of stakeholder dialogue sessions, involving users of composts from a number of different backgrounds. One of the key messages to come out of these meetings has been the need for comprehensive quality assurance systems to be set in place, so as to provide end users with the confidence that composts are produced consistently. Record keeping and quality control will therefore need to be improved at many sites.

The expansion of the UK composting industry thus seems to be inextricably linked to increased regulation and the need to adopt more stringent operational practices. Enclosed composting facilities seem likely to provide many of the solutions, as far greater degrees of both process and emission control can be achieved. Traceability of feedstocks and assurances about product quality will need to be demonstrated, especially if catering wastes and animal by-products are involved.

These changes will, however, only come at a cost, and it appears that economies of scale will begin to play a part. The structure of the composting industry therefore seems likely to change. Green wastes will probably continue to be processed at small-scale decentralised sites using the open-air turned-windrow method, whilst more difficult feedstocks will tend to be treated at larger-scale sites employing sophisticated enclosed systems; a pattern that mirrors that in mainland Europe. Such changes will, however, rely upon favourable legislative and economic frameworks – a position that has not yet been achieved in the UK.

Reference

Slater, R. A., Frederickson, J. & Gilbert, E. J. (2001). The State of Composting 1999 - Results of The Composting Association's survey of UK composting facilities and collection systems in 1999. . Wellingborough: The Composting Association.

WARD DEVLIEGHER

VLACO, Belgium

Vlaco is the Flemish Compost Organisation. Vlaco has been erected about 10 years ago, in answer to the introduction of selective collection and composting of bio- and greenwaste in Flanders. At that moment, compost was not well known or had a bad name because of a few existing MSW-composting plants. In the early 90's, MSW-composting was completely banned, while the selective collection and composting was stimulated and gradually increased. From an initial treatment of a few thousand tons of waste, composting has grown to over 700.000 tons of bio- and greenwaste being composted today. Today, people are better aware of the compost characteristics (see box) and the product is generally used as an organic soil improver, but also as an alternative for peat in potting media.

Compost characteristics

- High stable organic matter content
- Hygienised product, no weed seeds
- No impurities
- Fine product, easy to use

Together with an increased amount of biowaste- and greenwaste being collected, there has been an increased emphasis on and a strong stimulation of prevention and home composting as a tool to reduce the overall quantities of waste collected.

Initially, Vlaco had three major activities related to centralised composting: (1) marketing ("get people to know compost"), (2) quality assessment ("make sure compost is a quality product") and (3) research ("show how and for what purposes compost can be used"). As of today, prevention and home composting of organic waste have become a major task as well. All these activities had an important contribution in the overall evolution as mentioned above. Putting together marketing, quality assurance and research was particularly interesting to improve the general market acceptance for compost.

Table 1. Figures on organic waste treatment in Flanders

Amounts collected/treated *(kg inhabitant^{-1} year^{-1})*	**1981**	**1991**	**1993**	**1997**	**1998**
Selective collection	<20	74	115	268	312
⇒ ***composting***	*0*	*2*	*11*	*95*	*120*
Composting MSW	14	11	0	0	0
Incineration	75	146	140	132	217
Landfilling	187	174	193	125	
Total	296	405	449	526	529

The increased treatment of bio- and greenwaste has been an important strategy to lower the quantities of MSW that are disposed of (see Table 1). That is one main reason why composting should be really considered as a basic waste management option in treating the organic part of MSW.

The second main driving force for encouraging composting and compost production is the fact that it yields a sustainable source of stable organic carbon and slow-release nutrients. During the seminar, there were several nice examples of the benefits of compost use.

Although compost is often seen as a competing product for manure in agriculture, it should not. From different research projects that we have carried out, it was clear that for instance pig or cattle slurry in combination with compost can supply available nitrogen as well as stabile C. Such combinations gave good results as to crop yield, environmental protection (nitrate leaching) and soil fertility (improved C-concentration) (further information can be found in the contribution of Frank Nevens). There is plenty of evidence showing that it has its place in modern, sustainable agriculture. Furthermore, with N- and P-input limit values, farmers tend to maximize the input of readily available nutrients. In many cases, this might be a burden on carbon conservation or build-up in soil (see Annex 1). The use of compost has shown, even at seemingly low doses of 10 tons/ha/y, to be very suitable to conserve or improve the soil carbon content, even under these conditions.

At last, even if compost use would be difficult in agriculture or horticulture, there are plenty of other application areas (as is the case now in Flanders with only some 15% of compost that is applied in agriculture). The use of peat as an organic soil improver is for instance less sustainable than the use of compost. Compost is a fully recycled product that returns to the soil what has first been taken out. There is no addition of whatever in the ecosystem, except for C taken from the air by plants and entering the soil after composting. In this respect, there is indeed a need for compost.

Annex 1: evolution of organic carbon in arable soils in Flanders 1982 – 1999

The main service of the Soil Service of Belgium is to carry out soil samples and analyses and to give the associated fertilisation advice to farmers and horticulturists in Belgium. The Soil Service of Belgium has a long history of soil sampling, soil analyses and fertilisation advice. In order to have representative samplings, the Soil Service of Belgium has a network of trained and accredited soil samplers. As can be seen from Table 2, this generates a great number of samples each year.

One of the parameters that has been analysed over time is the organic matter content in soils. From the results obtained, an evolution in the organic matter content in arable soils over time can be depicted (Table 3). It is clear that especially over the last two measuring periods (1996-1999 in comparison with 1992-1995), a strong increase in the number of arable plots that are too low in organic carbon can be seen. One of the main reasons is likely the focus on the limits for nitrogen and phosphor input in arable plots. As a results, farmers tend to focus on fertilizers with a high percentage of readily available nutrients (and consequently a low amount of stabile organic matter).

Table 2. Number of soil samples taken in the 1996-1999 period

	Number of soil samples (1996-1999)
Sandy soils	18 489
Kempen	9 749
Sandy loam soils	27 611
Loamy soils	12 861
Polders (clay)	3 977

Table 3. Percentage distribution of organic matter content in arable soil samples for the 5 important agricultural regions in Flanders in different time periods.

Agricultural region	**Interpretation C-content[1]**	**1982-1985**	**1992-1995**	**1996-1999**	**% C**
Sandy soils	*Too low*	*30.3*	*30.8*	*39.3*	<1.8
	Favourable	50.4	49.8	45.4	1.8 - 2.8
	High	19.3	19.4	15.3	>2.8
Kempen (sandy soils)	*Too low*	*10.9*	*14.1*	*19.5*	<1.8
	Favourable	49.5	52.5	57.6	1.8 - 2.8
	High	39.6	33.4	22.9	>2.8
Sandy loam soils	*Too low*	*22.5*	*22.3*	*30.6*	<1.2
	Favourable	51.7	49.9	48.6	1.2 - 1.6
	High	25.8	27.8	20.8	>1.6
Loamy soils	*Too low*	*14.4*	*15.4*	*22.3*	<1.2
	Favourable	60.4	57.3	57.8	1.2 - 1.6
	High	25.2	27.3	19.9	>1.6
Polders (clay)	*Too low*	*21.3*	*28.7*	*31.6*	<1.6
	Favourable	47.4	44.3	44.5	1.6 - 2.6
	High	31.3	27	23.9	>2.6

[1] "Favourable" means that the carbon content is within the optimum range that has been determined by the Soil Service of Belgium. Too low are all results that are lower than the optimal range, "high" indicates all samples that have a carbon content above the optimum.

KARLA SCHACHTNER

German Federal Compost Quality Assurance Organisation, Köln, Germany

The German Federal Compost Quality Assurance Organisation (FCQAO) is recognised by the RAL-Institute as the organisation to handle monitoring and safeguarding of compost quality in Germany. To identify products of this standard, a quality label for compost (RAL-GZ 251) was created. The main task of the FCQAO is to guarantee an effective, continuous and at any time comprehensive monitoring of the keeping of quality requirements. Members of the FCQAO are public or private manufacturers of compost and other humus products as well as regional compost quality assurance organisations, whose members manufacture such products.

The production of composts from separate collection of organic waste from households, garden- and park areas took a rapid upswing in the past years. Today in over 400 compost plants participating in the quality assurance system of the FCQAO, annually approximately 4.5 million tons of compost raw materials are converted to specific compost products.

For creating a quality label of the RAL-Institute, consensus of all different stakeholders is required. This happened with the creation of the RAL-GZ 251 with the participation of more than 100 concerned groups and organisations. The external monitoring is a proof for the high quality of the products. At the same time the quality assurance guarantees the observance of waste, fertiliser and soil-protection regulations. For application recommendations, a special document (external super-vision certification - Fremdüberwachungszeugnis) is annually created for each product and each producer.

Experiences of the last years showed that the use of organic recycling products was not realised in a way, as due to the quality of the products and regarding the possible positive effects (improvement of the chemical, physical and biological characteristics of the soil, advantage effects on water regime, erosion susceptibility and workability etc.) would be desirable.

Therefore it is important that future regulations will have more emphasis on the positive effects of the compost application. The use of recycling products should be promoted if these products are competitive. One positive example is the request in the actual draft version of the Working Document "Biological treatment of biowaste" of the Directorate-General Environment. Here it is stated that public authorities and the public sectors should use compost as a substitute for peat and other raw materials extracted from the environment whenever possible.

It is also important, that new regulations will not prevent an increased use of compost. This includes a reasonable choice of the limit values for heavy metal contents. For precaution reasons limit values are at present discussed, which are based on average values. Parts of the stakeholders even propose limit values, which partly lay below the median (e.g. the limit value for lead as stipulated in the regulation (EC) 2092/91 for the organic sector). Due to seasonal fluctuations and analytic deviations between the laboratories there is a need to define values, which are approx. 50 to 100 % higher than the average values to ensure these limits (see Table 1 and 2). The corresponding statistical data of at present more than 20.000 analyses of compost samples may be obtained at the office of the German Federal Compost Quality Assurance Organisation.

Table 1. Heavy metal contents in compost and regionally caused deviations between the plants

Parameter	Average values of plants country wide (total average values)	Regional deviations between the plants		Regulation (EC) No. 2092/91
	[mg/kg dm] Measured values (1)	[coeff. of variat. %] Mean deviation (2)	Deviation to (3)	[mg/kg dm]
Pb	60,0	± 39 %	+ 196 % (178)	45
Cd	0,6	± 38 %	+ 165 % (1,6)	0,7
Cr	30,0	± 62 %	+ 530 % (189)	70
Cu	44,0	± 31 %	+ 118 % (96)	70
Ni	18,0	± 68 %	+ 477 % (104)	25
Hg	0,2	± 67 %	+ 640 % (1,5)	0,4
Zn	196,0	± 29 %	+ 184 % (362)	200
Mean		± 48 %		

(1) Average values of the plant average values of 164 composting plants (each last 10 analyses)

(2) Mean fluctuations between the plants

(3) Largest plant average value. Deviation from the country wide plant average value to (1) in % and absolutely in mg/kg dm (in brackets). Single analyses can be clearly higher.

Table 2. Ranges of contents of heavy metals within individual compost plants as well as possible error amounts with analytics

Parameter	Seasonal deviations within the plants		Possible analytic deviations
	[coeff. of variat. %] Mean deviation (1)	Deviation to (2)	Deviation to (3)
Pb	± 25 %	+ 58 %	± 29 %
Cd	± 27 %	+ 61 %	± 53 %
Cr	± 30 %	+ 65 %	± 52 %
Cu	± 22 %	+ 40 %	± 28 %
Ni	± 26 %	+ 57 %	± 24 %
Hg	± 46 %	+ 63 %	± 56 %
Zn	± 15 %	+ 64 %	± 19 %
Mean	± 28 %		± 37 %

(1) Mean fluctuations within the plants

(2) Largest deviation within a plant (90% percentile of the single analyses considered)

(3) By the example of the samples of the Interlaboratory Test 1995 of the German Federal Compost Quality Assurance Organisation.

Finally it is important that compost will be regarded as a product in a legal sense – under whatever conditions – so that it can be treated like other similar products in the market. Recycled products will have otherwise no chance to keep competitive in relation to products of primary raw materials. Self obligations of the economy, as the monitoring system of RAL, could build up a product certification and could be integrated for deregulation. The integration of self obligations in legislation can help to establish new systems or motivate producers to stronger participate in existing systems as the example of the German "Ordinance on Bio-Wastes - BioAbfV" has already shown.

REINER LATTEN

COPA/COGECA

First a preliminary remark

The return of organic residential waste such as compost to the cycle of nature is one of the most important ecological objectives of recycling and reuse of substances. In addition to the manifold wastes from industry and trade as well as domestic waste this applies also to recycling of by-products and waste from agriculture. This concerns beside compost i.a. sewage sludge, valuable animal proteins, processed oils and fats and crop residues. A precondition of recycling of the substances concerned is a proven and scientifically substantiated justification thereof.

Recycling is a complex matter. In agriculture the use of compost cannot be regarded just by itself but is to be integrated in the context of the agricultural application of organic residential waste, sewage sludge and other secondary raw materials. A politically motivated moral obliquity depending on the substance concerned is however not acceptable.

In this context two statements

1. Basically we, the farmers, are neither dependent on compost nor on sewage sludge.
These substances are dispensable in agriculture especially in view of the current hectic and partly dubious consumerism discussion.
2. If however recycling remains to be an ecological and social objective, then agriculture as a part of society cannot ignore it.

Nevertheless we have to insist on three prerequisites

1. The recycling – in our case e.g. sewage sludge or compost – must be scientifically justified. This pertains to the heavy metal content and persistent organic substances as well as to the hygienic innocuousness.
As an example the Bonn university together with the "Landwirtschaftliche Untersuchungs- und Forschungsanstalt der Landwirtschaftskammer" possesses long term analyses of sewage sludge from identified sewage treatment plants and samples of the corresponding soils. It became clear that the risks of sewage sludge from identified sewage treatment plants are calculable.

2. The 2nd prerequisite is the protection of farmers against a an incalculable ecological policy. Limit values and other legal stipulations are currently decided upon more and more not based on scientific insights, but for popular, opportunistic and topical political reasons. An example of this is the limit value for plant protective agents in the ground water of 0.1 µg l-1 water, which was legally fixed as "virtual zero value" without any scientific background and without benefit/risk evaluation.
In Germany the establishment of a State Sewage Sludge Compensation Fund for covering unforeseen damages could be achieved. The fund requires the government to make amends in

case of legal changes which are negative for the farmers. This legal obligation of the government also serves as a barrier to unjustified legal actions.

3. The use of sewage sludge and composts must be supported by society as it is an undertaking for society as a whole.
In addition to liability problems the social acceptance of the application of organic residential waste in agriculture is essential. If recycling is desired as an ecological objective and the agriculture assumes this social task, the possible negative consequences have to be borne by society as a whole. At the end of the day the farmer may not be the scapegoat for neglecting consumer and soil protection.

Also we should like to point out that in connection with the use of sewage sludge and compost there exists a paradox:

Because of extensive tests sewage sludge is calculable to the extent it originates from identified sewage treatment plants, in particular as input and output material are largely homogenous. In contrast the risks of using compost in agriculture are much less predictable. Not only various kinds of compost, as waste-, bio-, green-, and bark compost exist, but the individual kinds themselves vary considerably regarding material content.
The paradox is, that the image of the substances is the opposite of the test data: Whereas compost has a good image sewage sludge is generally frowned on.

The exaggerated discussion on BSE and consumer protection was very detrimental to our image. Not only the consumers but also the farmers are disoriented. This uncertainty affected the recycling of animal proteins, but also sewage sludge and composts.

The uncertainty in agriculture is further augmented if the hazard of the individual secondary material are assessed on the basis of moral obliquity. In this context the "Umweltbundesamt" (UBA) in Germany did suggest to terminate almost all recycling of sewage sludge. Furthermore according to UBA agricultural natural and mineral fertilisers should be assessed just as meticulously as sewage sludge. At the same time UBA declares compost to be generally inoffensive.

Such a dubious attitude by a federal agency does not resolve any social problems but undermines the confidence and the willingness of the farmers to cooperate in the area of recycling of valuable waste such as compost. Thus I arrive at the conclusion that the real problem is a policy which is no longer predictable.

Panel forum and open floor discussion

– Organic Matter Management & Sustainability – Do we need Compost ?

Delschen: (after presenting the key points; see written statement.) When compost is inappropriately used, there are unsustainable risks of pollutant accumulation and overload of nutrients. It is then necessary to balance positive and negative aspects: adjusting application rates in accord to good practices (nutrition) and limiting pollutant inputs. Some options could be to reduce inputs to output level or limit pollutant concentrations in compost to concentration in amended soils. This second option seems to be more realistic - but is it realisable?

Brøgger: During the meeting, lot of information on soil interactions was presented that could have an impact on legislation, work currently done and practices. In fact there is a range of knowledge that is not yet taken into account.

Delschen: Everything is not known yet so precautions should be taken. Let’s have a look at needs and benefits together, to find a compromise. Compost application should be limited to match nutrient effect and clear limits for pollutants in compost as far as possible. The major problem will be how to fix such limits. There is a lot of variation between composts across regions, processes analytical methods etc. It will then be difficult to guarantee values.

Devliegher: Using compost is OK, but if it is loaded with pollutants or nutrients, it is necessary to take a holistic view including manure, mineral fertilisation and so on. To consider only compost is then not enough in these cases. Considering actual farming practices it is not possible to produce anything without N, so we need to find a balance. A lot of heavy metals present in compost originate from the environment. We have to find how to recycle these from a global point of view, but we also have to avoid introducing more heavy metals into the ecosystems.

Bourmeau: All these question are important. Standardisation is necessary because analytical methods, reported at a recent sludge seminar in Brussels, agricultural practices and organic matter-needs are different in different countries. So, should we wait for new regulations and new methods? It is not possible to always wait. Sludge and compost represent relatively small amounts of material contaminated or potentially contaminated with heavy metals. There are large amounts of other organic matter, such as manure, that are equally problematic. Therefore, a global view is needed on protection, to consider all potential negative impacts of organic matter such as heavy metals, degradation or erosion. To fix limits of heavy metals, standardised analytical methods are needed, or the distortion between methods should be considered.

Caution is need in the preparation of legislation. For instance, the implementation of the new regulation on animal by-products forbids the composting of at-risk wastes unless in a closed reactor. Despite the potential environmental net-benefit this theoretically could mean the ‘death’ of composting of all governed wastes. The debate on soil protection soil fertility and public health needs to be more widely and openly discussed.

Marmo: Standardisation is an important question and the Commission is well aware of the problems that the non-harmonisation of standards may cause to the correct implementation of legislation. In order to address this issue, the Commission organised a workshop on standardisation that took place in 2001. Following that workshop, a Consortium was established in order to present a proposal for funding in order to develop horizontal standards in the fields of soil, sludge and compost. At the moment the proposal is not yet founded..

Latten: Considering nitrogen, mineral fertilisers are widely allowed and they scarcely have any problem with heavy metals (an exception is Cd in phosphoric fertilisers). In other fertilisers there are some problems (for instance Cd in tea, Cu in manure).

Brøgger: Limit values are needed to "guarantee" sustainability, but there are basic concepts of:

- Responsibility of both producers and users of products;
- Removing heavy metals from products;
- Composting only high quality raw materials and
- Communication of responsibilities at various levels, for products as well as composting processes.

van_Boxem: One can find on the Internet a publication that look at soil protection considering soil-FIST for the first time. There is a clear role of compost as a source of organic matter as soil organic matter is decreasing, with various resultant problems. Although not the primary element, compost can play a role by contributing various factors at one time:

- Adding organic matter to soil to prevent erosion;
- Improve to soil fertility and
- Enhance soil biodiversity.

The Commission have agreed The Sludge Directive in the context of soil policy and also biowaste recycling and this has implications for compost use..

Marmo: If I may be a little provocative, I would ask whether, as a matter of principle and policy, what originates from the soil should not go back to it. And better than asking *if* this should happen we should ask *how* it should happen, under which conditions and after what kind of treatment. Of course, contaminated raw materials should not go back to the soil but there is a fundamental principle of policy and responsibility to debate.

Floor: We should not forget that products will reach the consumer and then enter the food chain. One important problem also to be considered is that consumers react on feelings about things they do not know or understand. Of course we have to consider risks assessment in our assessment but we should not forget that the product will reach the market. From this point of view the use of sewage sludge is a problem irrespective of technical data. To restore consumers trust, we should indicate the type of raw material used for producing composts and their origins. Limits for pollutants are useful even if some are too low at present in Europe. This encourages the production of "clean products". Considering long-term recycling and sustainability of agriculture it is not possible to indefinitely add pollutants to soil as in the end the system will collapse.

In response a farmer representative stated that of course there are problems of acceptance, but also of fears and doubt. Farmers sometimes use some wastes that are not agronomically necessary but consider it a favourable disposal, benefiting the society we live in. In general, farmers are opened minded and could positively consider the recycling but with provisions:

- Not only farmers but all society is responsible;
- We need clear scientific statements and limit values to refer to and
- We need protection for farmers against badly calculated environmental policy. For example, limits of pollutants in waters may be divided by two, why? Because from a political point of view this will have a positive impact on public opinion. In Germany, protection exists for farmers that are recycling sewage sludge, so if limits change, the government should pay, which means changing limit will be decided only after extensive consultation. It must be the same for compost.

A lot of studies have been performed on sewage sludge, but for compost the situation is not as clear because of the wild heterogeneity of products linked to diversity of raw materials. It is not currently possible to make mathematical calculations and simulations, and so we need more knowledge.

Compost benefits from a good public image. This should not be spoiled by adopting a policy of recycling any less rigorous than that for sewage sludge. It is necessary to protect the public, but the public is uncertain in its opinion, which make the situation politically difficult.

Gilbert: A pollutant limit in compost-amended soils is needed. One question is how to take into account heavy metals interactions in the establishment of limits, and specifically, how to deal with compost compared to other materials.

Delschen: In Germany, all elements should be considered comparably, whether from mineral fertilisers, manure, compost or other sources. Some manure can also be considered as wastes.

Floor: soils can also be already harmed an so situation is different. We don't know much on compost unless that there are different qualities. So we need to inform the users on each product. We need to use it knowing its potentiality. If compost becomes a product and is no longer considered as a waste, the perception in public is different and it becomes much more competitive.

Devliegher: The Flemish system of control is well developed so that the difficulty of knowing compost from a general point of view is compensated by precise knowledge of each compost from each composting plant (minimum of 15 analyses / year/ plant). In addition the user of compost is identified so conditions of use are better controlled.

Floor: There is a policy on composts of biowaste, such that if the compost is in accordance with certain criteria, its origin is not important. This is not the same for composts of domestic solid wastes. For these it is important to match the appropriate compost for a specific situation - but is this compatible with a need for straightforward and broadly applicable advice to farmers?

Evans: As soon as the question is political, people speak of “The principle of precaution” and this is abusively used. In fact this principle is normally restricted to situations where knowledge is missing, yet a decision can be made. It should be accompanied by intensive research in appropriate areas to get the necessary information. Concerning waste-recycling we don't know everything but we do know enough to know the risks we take. Abusively using the “principle of precaution” to take a decision when valid knowledge is available destroys the trust of public and industry in decision-makers.

Floor: This appears to be the trend in environmental policy and legislation within Europe. It was stated that in 1986, domestic solid waste-derived compost was forbidden in Switzerland, because consumers no longer accepted them. The same question is now arising for sewage sludge and the government will be obliged to pay for incineration of organic wastes, and pay for replacing them by other organic fertilisers. Of course there is a need for quality and of appropriate use of compost, but for the public it is difficult to understand such definitions. In making any decision we should think of the public perception and create a forum for consultation. In the Swiss context information is available at www.vks-asic.ch

It is important to speak about the impact of composts on soils. Compost can contribute to soil preservation. What will be the developments in this area?

van Boxem: There has been a forum on soil in Naples, and consultation with the public (May / June 2001). Broader consultations in Autumn 2001 have also taken place. There will be further consultation in spring 2001. Later, advisers will be able to support the debate.

Brøgger: It is positive to consider separately the different and varied functions and interactions of soils.

Wallace: Working on compost market in the UK, there is a problem of acceptance by farmers and consumers. It is necessary to communicate to them the positive aspects of composts.

Agrey: In considering the economic actions programmed for 2010 there are 4 main areas: r

- Reduction of CO_2;
- Reduction of soil degradation;
- Reduction of NO_3 in water and the environment and
- Sustainable management of soil and biodiversity.

What about considering compost as a solution to all this?

Duckel: In agreeing with the Swiss way of considering the problem the view was expressed that products may have a positive impact, but nonetheless the production process and controls must be accepted by the public.

Latten: There is a question in Germany over who is responsible of the quality of produced food. Today we know that sewage sludge provides a mean of fertilising with calculable risks and that this is economically acceptable. This is not yet true for compost. It is necessary to match use to specific product quality and so is remains necessary to develop the qualitative approach in this area.

Floor[1]: It will be difficult to equalise the current position in Europe. For instance specific issues are already better understood and known in Germany compared to most Member States. In some other cases the approach is considered not always rational. In Switzerland some products are forbidden, yet some other present risks too. For example manure may have high amounts of heavy metals (Cu, Zn), while with sludge one can calculate the risk!

Devliegher: Soil analyses are performed regularly to help farmer to take decisions. Results show a decrease in soil organic carbon, even in regions producing a lot of manure. In these region manure is applied to soil and, as a consequence, compost is not used. As nitrogen input is limited, manure inputs are limited to a level where the carbon added by manure is insufficient. From this point of view this limit is not sustainable for soil preservation. How can we address the limit of Nha^{-1}? Where manure is not sufficient to increase C-level in soil, compost is definitely needed.

Floor[1]: In considering sewage sludge used in agriculture it is important to calculate the risk taken by farmers. The aim of this seminar was not to inflame the debate on whether applying organic wastes jeopardises the quality of soil and of production. However, in the long term it is a key responsibility of the whole of society that generates such wastes, including compostables, to contribute to and ultimately accept the outcome of the debate. Policies should be fixed to standardise the use of organic matter and wastes to reduce the negative impacts.

Brøgger: The responsibility of waste producers should not be underestimated. Of course we can consider that digested food results in sludge which re-enters agriculture. In addition, firms producing organic wastes, could also take a proportion of their waste and recycle this directly in production-unit, which in turn could be less expensive than buying new raw materials. It would be fair to create an incentive accessible to farmers recycling organic wastes for such sustainable economic practice.

Gallon: Reference was made to experiments presented in respect of the sustainability principle. Doses of up to 120tha^{-1} were noted and it was questioned whether this was excessive compared to typical practice? Also, in respect of the duration of experiments for 4-5 year - is this enough to check the sustainability of practices?

Feix (ADEME): Although there can be negative impact by using some wastes from pollutants such as heavy metals and we should take precaution to preserve soil quality, this should not slow down the use of “good” waste-derived material. Otherwise the only solution will be **incineration**. This is not a sustainable alternative. Work on “biowastes” should not be stopped, because more information is required.

Bourmeau: There is a large variation between composts because it is a product of raw materials and of processes that themselves both vary. The use of compost should reflect soil organic matter mineralisation rate, whether rapid or slow, and the crop. We should be precise when discussing about impacts as while fertilisers used for plant nutrition are applied at only several hundred of kgha^{-1} soil improvers are used at a dose of several tha^{-1}. Furthermore, growing media are used pure. Some years ago the only sources of organic matter were wastes, but this is no longer the case. There has to be progress towards practices of use that would increase the benefits and reduce the negative impacts of using all such material. In France, sources of organic matter are not sufficient to cover the needs.

Floor: It is necessary to speak about global climate change. In the long term, soil quality and, specifically, compost use, correspond to carbon sequestration in soil which is a very important component.

Marmo: In respect of climate change initiatives, the EU Commission and DG Environment in particular are working towards this.

If I may sum up some of the ideas voiced during these two days, I would say that actions for promoting better biowaste management include the following:

- For all environmental issues we have to better explain, especially to young people and students, what are good practices and how they can be a success.
- Environment protection is not simply about regulating the use of materials and wastes. In respect of composting, the problem is much more complex. It is necessary to integrate agriculture into composting and associated recycling industries and vice versa.
- Practices that are positive should be allowed, even for sewage sludge. It is necessary to find a balance between good and bad impacts or benefits and risks.

- It is necessary to develop communication of information to consumers and technology transfer to industry.
- Standardisation of sampling methods, analysis and traceability are needed.
- It is necessary to develop and implement voluntary agreements between farmers, composts producers and sewage sludge producers.
- It is necessary to take climate change into account.

I thank the participants and organisers for your input, which has allowed this event to be a success.

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