Chapter 11
Compost Use in Organic Farming

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Abstract Organic farming is a sustainable agricultural system that respects and relies on natural ecological systems. Its principles exclude the use of synthetic pesticides and fertilizers. Instead it is based on management practices that sustain soil quality and health. Composting of organic residues and the use of compost in agriculture bring back plant nutrients and organic matter to the soil that otherwise would be lost. Nevertheless, there are some potential risks associated with compost use, such as the accumulation of heavy metals or organic pollutants, which must not be neglected.

Some types of organic farms, such as stockless farms or vegetable farms, have difficulties sustaining soil humus using only organic farming sources. For such farms, using biowaste compost from separately collected organic household waste might be a solution, which in addition helps to close nutrient and organic matter loops of the whole society. Here we compile information on beneficial effects and potential risks associated with compost use and on crop yields and quality, with compost under an organic farming perspective.

The most important benefit of using compost is the increase in soil organic matter (SOM). Under temperate climate conditions, 6–7 t ha^{-1} $year^{-1}$ (dry wt.) compost is sufficient to maintain the soil humus level of medium-textured soils; higher rates increase the soil humus content. Regular compost addition enhances soil fauna and soil microbial biomass and stimulates enzyme activity, leading to increased mineralization of organic matter and improved resistance against pests and diseases, both features essential for organic farming. Through the significant increase in the soil's content of organic carbon, compost fertilization may make agricultural soil a carbon sink and thus contribute to the mitigation of the greenhouse effect.

Phosphorus and potassium in compost become nearly completely plant-available within a few years after compost application. The nitrogen-fertilizer value of compost is lower. In the first years of compost application, N mineralization may

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vary from −15% to +15%. Nitrogen recovery in the following years depends on the site- and cultivation-specific mineralization characteristics and will roughly be the same as that of soil organic matter (SOM).

Soil cation exchange capacity (CEC) increases with compost use, improving nutrient availability. Moderate rates of compost of 6–7 t ha^{-1} year^{-1} dry wt. are sufficient to substitute regular soil liming. In the available micronutrient status of the soil, only minor changes are to be expected with high-quality composts. Increasing soil organic matter exerts a substantial influence on soil structure, improving soil physical characteristics such as aggregate stability, bulk density, porosity, available water capacity, and infiltration. Increased available water capacity may protect crops against drought stress.

Plant-disease suppression through compost is well established in container systems. In field systems, the same processes involving the suppression of pathogens by a highly active microflora supported by the supply of appropriate organic matter are likely at work.

When using high-quality composts, such as specified by the EU regulation 2092/91, the risk of heavy metal accumulation in the soil is very low. Nitrogen mineralization from compost takes place relatively slowly and there are virtually no reports of uncontrollable N-leaching. Concentrations of persistent organic pollutants such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), or polychlorinated dibenzodioxins and dibenzofurans (PCDD/F) in high-quality composts usually approach the usual soil background values. Also the overall hygiene and hygiene concerning plant diseases and weeds are not a problem if quality composts produced in a monitored system are used.

Most studies found positive yield effects of biowaste compost. However, the effect of biowaste compost applied at moderate rates usually takes some years to develop. It depends on the factors determining nutrient mineralization from soil and compost and also on crop-related factors such as the nutrient requirements and uptake dynamics of the respective crop rotation. Crops with longer growth periods can make better use of compost. Many vegetable crops respond favorably to compost fertilization, often immediately after the first application. Crop quality is usually not affected by compost fertilization in cereals and slightly positively influenced in vegetable crops.

Keywords Soil humus • nitrogen • phosphorus • potassium • soil structure • heavy metals • organic pollutants • yield • crop quality • compost • organic farming • Cd • Zn • Ni • Pb • Hg • Cu • Cr • PAH • dioxin • CEC • soil pH • soil N • nitrate, P, K • micronutrients • soil aggregate • soil water • plant disease • maize • wheat • barley • potato • tomato broccoli • cabbage • cauliflower • cantaloupe • legume • onion

11.1 Introduction

Organic farmers do not use synthetic fertilizers and pesticides but seek to augment ecological processes that foster plant nutrition and yet conserve soil and water resources. Maintaining and improving the soil's quality and fertility are central to organic farming (EU regulation 2092/91). Therefore, practices that add organic material are routinely a feature of organically farmed soils to sustain soil humus as the basis of soil's natural fertility.

One of the principles of organic farming is to close the nutrient cycles in the farm. However, there is some controversy among organic farmers about whether the principle of the closed nutrient cycle is to be regarded in a strict sense and external inputs to the farm are to be minimized or whether nutrient cycles may also include the consumers of agricultural products and biowaste compost from separately collected organic household wastes may be returned to an organic farm, thus closing the larger loops of nutrients and organic matter of the whole society. There are some types of organic farms, such as stockless farms or vegetable farms, which find it difficult to sustain the humus content of their soils. In other cases, management before conversion has left a soil organic-matter content too low to ensure soil functions. For such farms, and for farms that are unable to remedy some nutrient deficiency through organic farming sources such as manure or leguminous crops, the use of high-quality biowaste compost might be a viable alternative.

In organic farming, only the following types of compost are allowed:

- Compost from organic material derived from organic farms is permitted without restrictions.

Other composts, such as listed below, may be applied only if adequate nutrition of the crop being rotated or soil conditioning is not possible by the methods listed in the regulation. The need for such composts must be recognized by the inspection body.

- Composts from animal excrements (factory farming origin forbidden)
- Composts from mixtures of vegetable matter
- Composted bark from wood not chemically treated after felling
- Compost from source-separated household waste, produced in a closed and monitored collection system and not exceeding the following heavy metal limits (in mg/kg dry matter): Cd 0.7, Cu 70, Ni 25, Pb 45, Zn 200, Hg 0.4, Cr_{tot} 70, Cr (VI) 0 (EU regulation 2092/91).

The aim of this study is to compile the information on compost use, which is documented in scientific publications, under an organic farming perspective.

11.2 Beneficial Effects of Compost Use

11.2.1 Soil Organic Matter

The most important benefit of using compost is the increase in soil organic matter. Most arable soils contain only 2–4% organic matter by weight, yet very little about these soils is not significantly influenced by the organic matter in them. Organic matter provides much of the soil's capacity to store nutrients and water. It plays a critical role in the formation and stabilization of soil structure, which in turn produces good tilth and drainage and resistance to erosion. It cannot only carry and make available nitrogen, sulfur, and phosphorus but also improve the availability of nearly all nutrients, whether applied as fertilizer or weathered from minerals. It promotes the health of the soil ecosystem and stimulates organisms that cycle carbon and protect plants from disease (Weil and Magdoff 2004).

The concentration of organic matter in soils is primarily related to climate (temperature and precipitation), to soil texture (clay content) and to soil drainage status. Crop rotation and management usually play a smaller, but important role (Shepherd et al. 2002). Organic matter accumulation in soils is maximum when the difference between annual plant productivity and annual decomposition is highest. In cropped soils, organic matter accumulation also depends on the balance between what is exported from the soil and what remains as residues. Low mean annual temperatures tend to slow decomposition much more than productivity. Within limits, more rainfall tends to increase plant growth more than it does decomposition; therefore, soil organic matter tends to be positively correlated with annual precipitation. If environmental factors are similar, finer-textured soils tend to accumulate higher amounts of organic carbon (Weil and Magdoff 2004).

Nearly all the nitrogen and large proportions of the phosphorus and sulfur found in soils occur as constituents of soil organic matter. The soil organic matter serves as both the principal long-term storage medium and as the primary short-term source of these and other nutrients. The nutrients in soil humus are transformed into plant-available forms by microorganisms. Humus exerts important physical effects on the soil. It promotes the formation of a stable aggregate structure, which improves soilwater-holding capacity and aeration. Humus itself also has a high water-holding capacity. Humic substances buffer the pH of the soil. The dark color of the uppermost soil layer, which is due to humic substances, promotes soil warming in spring and thus elongates the growth period. A high humus content allows also moist soil to be tilled without causing compaction (Golueke 1975; Schachtschabel et al. 1998; Stevenson 1982; Weil and Magdoff 2004).

Soil organic matter is subject to biochemical decomposition and transformation and there are different levels of fragmentation, transformation, and biodegradation. Parts of newly added organic material, which are of greater stability, may persist for many years in the soil. Some of the functions of soil humus, however, are not due to the long-term persistance of soil organic matter (SOM), but to its permanent turnover and short-lived metabolic products. The maintenance of a large and active soil microflora, for instance, which mineralizes nitrogen and mobilizes other nutrients, depends on a repeated supply of organic material (Sauerbeck 1992). A relatively small portion of soil organic matter with a half-life measured in months or a few years accounts for most of the biological activity in soil and plays a particularly important role in maintaining soil quality. The active pool of soil organic carbon provides the fuel that drives the soil food web (Weil and Magdoff 2004). A significant increase in the soil's content of organic carbon may make agricultural soil a carbon sink and thus contribute to the mitigation of the greenhouse effect.

The profound effects that organic matter has on almost all soil properties make soil organic matter management on the farm the basis for sustainable agricultural production. In general it is assumed that between 1% and 5% of the soil organic matter, depending on the kind and intensity of soil cultivation, are mineralized annually in temperate climate agroecosystems. In order to maintain the soil's humus level and to refill the active pool of soil organic carbon, which nourishes the soil food web, at least the same amounts of organic matter must be added to the soil every year.

Compost typically has a high organic matter content and organic matter in well-cured compost is highly humified, its C/N ratio being similar to that of soil humus. Compost organic matter contents range between 15% and 50% d.m. (dry matter) and humic acid contents between 15% and 45% o.d.m. (organic d. m.) (Diez and Krauss 1997; Smidt and Tintner 2007; Zethner et al. 2000). Therefore, well-cured compost has a very high humus-reproduction value (VDLUFA 2004; Leithold et al. 1997; Kolbe 2007).

11.2.1.1 Humus Content

Numerous experiments show that compost fertilization regularly leads to a distinctive increase in the humus content of the soil. Such increases were reported from field trials with 1–28 years duration, with annual compost applications ranging from 6 to 90 t ha^{-1} and situated on a broad range of sites and soil types.

One year after application of 80 t ha^{-1} compost made from the organic fraction of household waste to an infertile Rensic Leptosol near Madrid, Spain, soil organic carbon was significantly increased (by 9 g kg^{-1}) as compared to the untreated control (Illera et al. 1999).

In 3-year compost field trials situated near Kassel, Germany, biowaste compost was applied at rates of 30 and 100 t ha^{-1} year^{-1} (wet wt.), respectively, to a sandy soil and to a loamy silt loess soil. On the sandy soil, soil C_{org} increased from 14.3 to 14.5 and 16.5 g kg^{-1}, respectively. On the loamy silt loess soil, soil C_{org} increased from 11.0 to 13.0 and 17.8 g kg^{-1}, respectively (Stöppler-Zimmer and Petersen 1997).

When 30 t ha^{-1} (wet wt.) compost from pruning waste and crop residues was applied to each of five crops during a 3-year experiment on a loam soil with a vegetable rotation near Seville, Spain, soil total organic carbon increased from 7.8 to 13.5 g kg^{-1}, while in the treatment with mineral fertilization, C_{org} amounted to 8.5 g kg^{-1} (Melero et al. 2007).

Timmermann et al. (2003) conducted six field trials with biowaste compost for 5 and 8 years, respectively, on mostly silty loam soils in Baden-Württemberg, Germany, under a maize–winter wheat–winter barley rotation.With annual biowaste-compost applications the C_{org} content of the soil increased by 1.3 g kg^{-1} C_{org} per 5 t ha^{-1} (dry wt.) of compost applied on average.

Clark et al. (1998) investigated the changes in soil quality during the transition from conventional to organic farming on silty loam in Sacramento Valley, USA. The organic treatment received 4–7 t ha^{-1} (dry wt.) composted manure every second year and vetch cover-crop residues every fourth year. After 8 years, soil total carbon content in the organic treatment had increased significantly from 9.11 to 10.21 g kg^{-1}, while it remained the same in the conventional treatment.

Biowaste-compost fertilization in organic farming (at average annual rates of 6, 11 and 16 t ha^{-1} dry wt.) was compared to conventional mineral fertilization and to no fertilization on a silty loam Fluvisol near Vienna, Austria. The crops grown were mainly cereals, with potatoes every fourth year. After 10 years, soil organic carbon content had increased from 19.9 to 20.5–21.7 g kg^{-1} in the three treatments with increasing rates of biowaste-compost fertilization, while it remained the same with mineral fertilization and decreased to 18.3 g kg^{-1} without fertilization (Hartl and Erhart 2005), Fig. 11.1.

Diez and Krauss (1997) recorded increases in soil C$_{org}$ content from 14.5 to 16.9 g kg^{-1} on a loamy loess soil and from 19.2 to 22.2 g kg^{-1} on a gravelly soil, with an average annual input of 4.4 t ha^{-1} organic matter (in 14.8 t ha^{-1} compost dry wt.) in field experiments of 20 years duration, under the humid climatic conditions of Bavaria, Germany. The crop rotation of the experiments included sugar beet/potatoes, winter wheat, and summer barley.

The DOK-experiment in Therwil, Switzerland, compares, among other treatments, fertilization with composted manure at a rate corresponding to 1.4 livestock units in biodynamic farming with conventional mineral fertilization on a sandy loam Luvisol. The crop rotation includes potatoes + green manure, winter wheat + intercrop, cabbage/beets, winter barley, and 2–3 years grass clover. After 21 years of compost fertilization, soil organic carbon had increased by 1% in the biodynamic treatment (using manure compost), while the soils in the organic treatment (with rotted

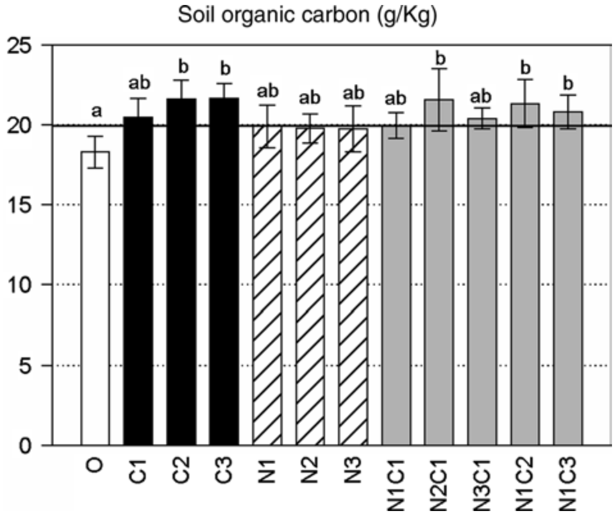

Fig. 11.1 Soil organic-carbon contents (g kg^{-1}) at 0–30 cm depth in spring 2003 (*bars*) as compared to the initial level in spring 1993 (*horizontal line*: 20 g/kg). Treatments with the *same letters* are not significantly different at $P \leq 0.05$ (From Hartl and Erhart 2005. With permission from Wiley-VCH)

manure) and in the conventional treatment with manure had lost 9% and 7% of their C_{org}, respectively. With mineral fertilization 15% and with no fertilization 22% of soil C_{org} were lost (Fliessbach et al. 2007). Although the crop rotation included plenty of green manuring, intercrops, and grass clover, additional compost fertilization distinctly increased soil humus content.

No significant increases in soil humus were found in 3 years' trials with moderate annual inputs (24 and 30 t ha^{-1} year^{-1} wet wt., respectively) on a Cambisol (Ebertseder et al. 1997) and on sandy podsols and gley soils (Boisch 1997), most probably due to the low clay content of the soils and the short duration of the experiments.

From these experimental results it may be concluded that in general for medium-textured soils under temperate climate conditions, around 6–7 t ha^{-1} year^{-1} (dry wt.) of compost application are usually sufficient for the maintenance of the soil humus level; higher rates increase the soil humus content.

11.2.1.2 Humus Composition, Soil Microbiology, and Soil Fauna

Besides the effects of compost fertilization on the total humus content of the soil, there are also effects on the composition of soil organic matter. Humus fractionation showed that the humin fraction with compost application was approximately 50% higher than in the other soils of the study (Fliessbach et al. 2000). Microbial biomass C and N as well as their ratios to the total and light fraction C and N pools in the soils of the organic systems were higher. This is interpreted as an enhanced decomposition of the easily available light fraction pool of soil organic matter, which points to a more efficient utilization of organic matter by a large and diverse microbial biomass (Fliessbach and Mäder 2000; Mäder et al. 2002). Composts are very diverse in respect of their feedstocks; they are in different stages of biodegradation and of different biochemical composition, such as their contents of soluble C, cellulose, and lignin. The type and diversity of plants and organic residues added to a soil can influence the type and diversity of organisms that make up the soil community, and vice versa (Weil and Magdoff 2004). Soil microbial populations are also altered through the addition of the compost microflora (Ros et al. 2006).

Regular addition of organic matter (compost) increases soil microbial biomass and stimulates enzyme activity (Fliessbach and Mäder 2000; Lalande et al. 1998; Pascual et al. 1997; Schwaiger and Wieshofer 1996; Serra-Wittling et al. 1995), leading to increased mineralization of organic matter and improved resistance against pests and diseases. By providing an additional food source compost fertilization also enhances earthworm abundance and biomass (Kromp et al. 1996; Mäder et al. 2002; Pfotzer and Schüler 1999).

11.2.1.3 Cation Exchange Capacity

Negatively charged soil particles such as clay minerals and humic substances are able to adsorb cations. Adsorbed cations are kept in a status in which they cannot be leached, but may only enter the soil solution through exchange for other cations. Only after that they may be leached or taken up by plants. This property enables soils to hold nutrients in the soil–plant cycle or at least to delay their being lost into adjacent ecosystems (such as lakes and rivers or groundwater). The total exchangeable cations are referred to as the cation exchange capacity (CEC). Soil CEC is greatly influenced by the input of organic matter. The average CEC of organic matter is 2 $\mathrm{mmol_c\ g^{-1}}$, whereas the CEC of clay is around 0.5 $\mathrm{mmol_c\ g^{-1}}$ and that of silt around 0.1 $\mathrm{mmol_c\ g^{-1}}$ (Schachtschabel et al. 1998).

In an experiment with biowaste-compost fertilization at average annual rates of 15–39 t $\mathrm{ha^{-1}}$ (wet wt.), the CEC was closely correlated with the humus content of the soil and increased linearly with the amount of organic matter added via compost during 5 years. Compared with the unfertilized control, CEC rose by 3–7% in the compost treatments. In the treatments receiving mineral fertilizer only, the CEC was the same as in the unfertilized control. In a second experiment, with compost application at a total rate of 130 t $\mathrm{ha^{-1}}$ compost in different doses and intervals during 6 years, CEC increased by 4–10%, in proportion with the increase in humus content (Hartl and Erhart 2003).

Also Businelli et al. (1996) recorded a significant increase in CEC in a 6-year experiment on a clayey loam soil near Perugia. The same was reported by Frohne (1990) after a single application of 240 t $\mathrm{ha^{-1}}$ biowaste compost on a compacted loess Luvisol.

11.2.2 Soil pH

Biowaste-compost pH is usually around 7.5–7.8 (Timmermann et al. 2003; Vogtmann et al. 1993a; Zethner et al. 2000). Numerous field experiments show that compost fertilization increases the soil pH in acidic soils (Alin et al. 1996; Hue et al. 1994; Timmermann et al. 2003) and slightly acidic soils (Alföldi et al. 1993; Diez and Krauss 1997; Ebertseder et al. 1997; Stöppler-Zimmer and Petersen 1997; Timmermann et al. 2003). In neutral to slightly alkaline soils pH is usually unaffected (Diez and Krauss 1997; Erhart et al. 2002; Timmermann et al. 2003).

In summary, the amount of base-forming cations supplied to the soil with the application of moderate doses of compost (6–7 t $\mathrm{ha^{-1}\ year^{-1}}$ dry wt.) is sufficient for the maintenance or a slight increase in pH, and therefore can substitute regular soil liming.

11.2.3 Nitrogen

11.2.3.1 N Mineralization

On average, biowaste compost contains 11.5–16.4 g $\mathrm{kg^{-1}}$ total nitrogen (Timmermann et al. 2003; Vogtmann et al. 1993a; Zethner et al. 2000), which is present mostly in humus-like organic compounds. More than 90% of total compost N is bound to the organic N pool (Amlinger et al. 2003a). Between 30% and 62% of the total N of biowaste and yard-waste composts are present in humic acids (Smidt and Tintner 2007).

Therefore, a large portion of the nitrogen present in compost is not readily available to plants, but it can to a certain degree be mineralized and subsequently be taken up by the plant, or immobilized, denitrified, and/or leached. N mineralization from composts is affected by the same factors that affect the N mineralization of organic N in soils. Compost-related factors include the C and N content of the compost, the C/N ratio, the biodegradability of compost C and the compost microflora. The biochemical composition, such as contents of soluble C, cellulose, and lignin, appears to play a crucial role for mineralization (Gagnon and Simard 1999, Mary et al. 1996). For instance, compost organic N derived from vegetal tissues was much more resistant to mineralization than organic N derived from animal wastes (Canali et al. 2003). Site-related factors include soil texture, pH, and climate.

The N-mineralization rate of composts can be determined either in incubation experiments or in pot or field trials. In the latter, nitrogen uptake by the compost-fertilized crop is compared to that of a crop without fertilization or with mineral N fertilization. In incubation experiments using composts from different feedstocks and of varying maturity, N-mineralization rates ranging from −30.3% to +14.3% of the organic N were recorded (Chodak et al. 2001; Gagnon and Simard 1999, Hadas and Portnoy 1997, Siebert et al. 1998). In general, incubation experiments show that N-mineralization rates of mature composts are higher than of immature composts. In pot studies with compost-amended soil, plant N recovery ranged from 2% to 15% (Hartz and Giannini 1998, Iglesias-Jimenez and Alvarez 1993, Scherer et al. 1996).

In field experiments, mineralization is further influenced by soil-cultivation measures and plant–soil interactions, and so it is important to know this dynamic to adjust the time of the compost application. The N uptake of field crops depends also on the respective crop N requirements and N-uptake dynamics. Therefore, N mineralization calculated from the results of field trials varied from −14% to +15% (Brandt and Wildhagen 1999; von Fragstein and Schmidt 1999; Gagnon et al. 1997; Hartl and Erhart 2005; Nevens and Reheul 2003). High N-mineralization and N-recovery rates are reported when N-rich, well-biodegradable composts and/or crops with high nutrient demand and a long growth period are used, while immature composts and yard-waste composts with low N content usually show low N-mineralization and N-recovery rates.

Subsequently, the remaining portion of compost N and compost humus is incorporated into soil humus. Therefore, on the longer term, the mineralization rate of this portion will be the same as that of soil organic matter.

A survey of numerous field experiments showed, that nitrogen recovery in the first year after compost application was between 2.6% and 10.7% (Amlinger et al. 2003b). Therefore, around 5% of the compost N may be assumed to be plant-available in the first year. Nitrogen recovery in the following years was dependent on the site- and cultivation-specific mineralization characteristics and was around 2–3% of the compost N applied (Amlinger et al. 2003b).

One strategy therefore might be to apply compost to leguminous cover crops. Legume residues decompose quickly and provide available nitrogen whereas compost decomposes more slowly and contributes more to organic matter buildup. Targeting the application of compost to a legume or mixed legume–grass crop permits the legume to act as an N buffer against the variable or negative N release from composts (Lynch et al. 2004). Incorporating residues with a range of C/N ratios can lead to the timely mineralization of available soil N for crop uptake.

Sanchez et al. (2001) found that nitrogen mineralization (of the same added material) was distinctively higher in a diverse system which had received diverse crop residues plus composted manure than in a conventional corn plus mineral-fertilizer system. Also Drinkwater et al. (1998) showed that the application of relatively diverse residues that differ in terms of biochemical composition can significantly increase soil C while meeting crop N needs. On the other hand, applying compost to leguminous cover crops might also buffer excess nitrogen to reduce the risk of N-leaching (Lynch et al. 2004).

Organic sources of N, such as manures, composts, or legume cover crops, can furnish adequate crop nutrition to full-season crops while maintaining relatively low levels of available N for most of the growing season. On the other hand, N mineralization from organic sources might lag behind in the needs of early short-season crops and might continue in the fall after full-season crops have been harvested. Therefore, when organic sources of fertility are used, additional available N might be needed for early-season crops, and catch crops should be used to prevent excess N-leaching following the growing season (Magdoff and Weil 2004).

Due to the large amounts of organic matter present in compost, significant increases in soil total nitrogen content are quite common with compost fertilization. Such increases were reported from numerous field trials on a broad range of sites and soil types (Alin et al. 1996; Businelli et al. 1996; Cortellini et al. 1996; Diez and Krauss 1997; Hartl and Erhart 2005).

11.2.3.2 Nitrogen-Leaching

For one, the increased mineralization potential which results from the rise in soil total nitrogen content is desired and necessary in organic farming in order to feed the crop plants from the soil resources, but for another, it holds the risk of increased nitrogen-leaching to the groundwater. Several experiments, conducted under varying soil and climate conditions, showed that compost fertilization usually resulted in equal or lower nitrate-leaching losses than corresponding mineral fertilization.

With compost fertilization at rates of 43 and 86 t ha^{-1}, respectively, drainage water nitrate concentrations in the first year were not significantly different from the unfertilized control, which amounted to 5.2 ppm, while with mineral N fertilization at 400 kg ha^{-1}, drainage water nitrate concentrations increased to 41.5 ppm. Maize grain yields with compost were the same as in the control, while they increased significantly with mineral fertilization. In the second year, when neither compost nor mineral fertilizer was applied, NO_3-leaching losses of the mineral fertilized treatments were still 300% of those in the compost-only treatments. Wheat yields in the compost treatments were twice and three times, respectively, as high as in the control. In the mineral fertilizer treatment wheat yields amounted to 170% of those without mineral fertilizer (Pardini et al. 1993). When five different fertilization regimes were applied to lysimeters filled with sandy soil, total nitrate-leaching losses decreased in the order mineral fertilization, fertilization with manure compost, refuse compost, unfertilized, yard-trimmings compost. Cumulative nitrogen export through the crops decreased in the same order (Leclerc et al. 1995). Small lysimeters were fertilized during 6 years with composts of varying origin (Jakobsen 1996). When the residual effect was tested in the seventh year without fertilization, NO_3-leaching losses were higher in the lysimeters with compost owing to the decomposition of compost in the soil. After a new fertilization, however, NO_3-leaching losses were smaller in the lysimeters with compost than in those with mineral fertilization. Dry matter yields of barley in the last experimental year were 50% higher with mineral fertilization than with compost.

Nitrate in groundwater was measured beneath a 3-year field trial with vegetables on a sandy soil over a shallow groundwater table (Maynard 1993). Nitrate concentrations in the groundwater were lower in the compost treatments (with annual rates of 56 and 112 t ha^{-1}, sufficient to provide the fertilizer requirements for intensive vegetable production) than in the control plots, which had received mineral fertilizer. In 3-year field experiments with biowaste compost on podsolic, gley-podsolic, and Luvisol soils in Northern Germany, none of the compost treatments (total application 26 and 42 t compost ha^{-1}) resulted in clear increases in soil water nitrate contents (Boisch et al. 1993). Yields in the compost treatments were not significantly higher than in the unfertilized control in most years (Boisch 1997). Nitrate concentrations in soil water in a field experiment with yard-trimmings compost, manure, manure compost, and mineral fertilization were also similar in all treatments on a Luvisol in Switzerland and the same was true for the yields (Berner et al. 1995). With biowaste-compost fertilization at 16 and 23 t ha^{-1} $year^{-1}$, respectively, on average of 11 years, nitrogen-leaching to the groundwater as determined using ceramic suction cups was not increased as compared to mineral fertilization at 41 and 56 kg N ha^{-1} $year^{-1}$, respectively, in an 11-year crop-rotation experiment on a Molli-gleyic Fluvisol near Vienna, Austria. Even intensive nitrogen mineralization during a 4-month period of bare fallow did not cause pronounced differences between the fertilization treatments (Erhart et al. 2007). The yields did not differ significantly between compost and mineral-fertilizer treatments in most years (Erhart et al. 2005).

The results of these experiments show that normally compost fertilization does not pose a risk for groundwater eutrophication. N mineralization from compost takes place relatively slowly and there are virtually no reports of a sudden, ecologically problematic rise in soluble N pools and uncontrollable N-leaching.

11.2.4 Phosphorus

Phosphorus concentrations in biowaste composts generally range from 2.7 to 4.0 g kg^{-1} (Timmermann et al. 2003; Vogtmann et al. 1993a; Zethner et al. 2000). On the one hand, composts enrich the soil phosphorus status by their direct contribution, as 20–40% of the P in compost is immediately plant-available (Vogtmann et al. 1993a). Organic P in composts from plant materials is readily decomposed to release ortho-phosphate, which is available to plants (He et al. 2001). But organic matter does not only provide a source of P from mineralization but also can reduce the capacity of acid soils and of soils with a $pH > 8$ to lock up P by fixation. Organic soil amendments reduce the sorption of P in soils and increase the equilibrium P concentration in the soil solution (Hue et al. 1994; Weil and Magdoff 2004).

Increased soil contents of available P frequently occur after compost application (Businelli et al. 1996, Cortellini et al. 1996, Diez and Krauss 1997, Parkinson et al. 1999). With application of 39 t ha^{-1} $year^{-1}$ (wet wt.) biowaste compost, plant-available soil contents of phosphorus were significantly higher than in the unfertilized control. In the treatments which had received 27 and 15 t ha^{-1} $year^{-1}$ the soil contents of plant-available phosphorus were in the same range as with 48 kg P_2O_5 ha^{-1} $year^{-1}$ in mineral superphosphate or triplephosphate fertilizer. Also plant phosphorus contents showed that the phosphorus supply with compost fertilization was approximately as high as in the mineral fertilizer treatments (Hartl et al. 2003). In the DOK experiment, soluble fractions of phosphorus were lower in the compost treatment than in the conventional treatment, but the flux of phosphorus between the matrix and the soil solution was highest in the system with compost application. Phosphorus flux through the microbial biomass was faster in compost-treated soils, and more phosphorus was bound in the microbial biomass (Mäder et al. 2002; Oehl et al. 2001).

Phosphorus availability is crucial for optimum N fixation by legumes. Green-waste compost, applied on acid soils (pH 5.4) very low in P, provided sufficient P for red clover to achieve optimal nitrogen fixation. The effect of green-waste compost was nearly equivalent to that of triple-superphosphate (Römer et al. 2004).

Most studies found that P in compost became nearly completely plant-available within three vegetation periods after compost application (Amlinger et al. 2006). Therefore, it may be concluded that the total P content of composts can be calculated as a substitute for mineral P fertilization.

11.2.5 Potassium

The concentrations of potassium in composts vary from 8.4 to 12.5 g kg^{-1} (Timmermann et al. 2003; Vogtmann et al. 1993a; Zethner et al. 2000), depending on different sources of feedstocks. Green-waste compost, for example, often exhibits elevated K contents. However, the composting process may also have a substantial influence on K availability. Due to the high water solubility of K, leaching losses may occur if the compost is exposed to rainfall. Immediate plant availability of K in composts can be more than 85% of the total K content (Vogtmann et al. 1993a) and the remainder is easily mineralizable.

Soil contents of available K typically increase with application of composts made from plant residues (Businelli et al. 1996, Cabrera et al. 1989, Diez and

Krauss 1997, Parkinson et al. 1999). For example, application of 27 and 39 t ha^{-1} $year^{-1}$ (wet wt.) of biowaste compost for 5 years significantly increased plant-available soil contents of potassium in a field experiment in Austria, while they remained the same in the control and increased slightly, not significantly with mineral fertilization at rates of 74 kg K_2O ha^{-1} $year^{-1}$. Plant potassium contents showed that the potassium supply with compost fertilization was approximately as high as with mineral fertilization (Erhart et al. 2003).

In the DOK experiment, under rather humid conditions, soluble fractions of potassium were lower with manure-compost fertilization than in the conventional treatments (Mäder et al. 2002).

Clear increases in plant-available soil potassium contents were found in field experiments in Baden-Württemberg (Timmermann et al. 2003). Average compost rates of 10 t ha^{-1} (dry wt.) $year^{-1}$ were sufficient to counteract or even overcompensate the decrease in soil potassium contents caused by plant uptake and leaching.

From these findings it may be concluded that the total K content of composts can be accounted for in the fertilizer calculation.

11.2.6 Micronutrients

Iron (Fe), Mn, Cu, Zn, B, and Mo are essential elements for crop production and food quality (Marschner 1995). A long-term diet containing low concentrations of Fe, Mn, Cu, and Zn has been reported to cause human malnutrition. The availability of Fe, Cu, and Zn in calcareous soils is generally low, and an external source of these nutrients is needed for improved crop yield and food quality (He et al. 2001).

Addition of organic matter to soil can either decrease or increase metal availability, solubility, and plant uptake. Insoluble organic matter usually forms insoluble organometal complexes or sorbs metal ions, making them less available for plant uptake or leaching. However, many organic amendments have a soluble C component or produce soluble decomposition products, and the soluble organic matter can increase metal solubility by forming soluble organometal complexes. Metals are also released through the biodegradation of organic matter by microorganisms. The influence of soil organic matter on metal mobility can also be modified by the solution pH (Weil and Magdoff 2004). Crops, and even cultivars, differ considerably in their sensitivity to individual trace elements, and within the plant, trace elements are not uniformly distributed among plant tissues (Adriano 1986).

Incorporating a municipal-waste compost at 48 t ha^{-1} or a municipal-waste biosolids co-compost at 24 t ha^{-1} into a calcareous limestone soil increased concentrations of soil-extractable metals, but caused no significant changes in tomato and squash (*Cucurbita pepo* L.) fruit concentrations of Cu and Zn compared to an unamended control (Ozores-Hampton et al. 1997).

Leaves of tomato plants grown in soil amended with municipal-waste compost showed decreased Mn and Cu contents compared to leaves from plants grown in unamended soil in a study by Stilwell (1993). These results were attributed to reduced availability of Mn and Cu in the compost-amended soil due to increases in pH and organic matter content.

In the DOK experiment in Switzerland, amounts of plant-available Mn, Zn, and Cu in the sandy loam Luvisol (measured using $CaCl_2$/DTPA extraction) were not significantly different between the organic and biodynamic treatments receiving rotted and composted manure, respectively, and the mineral fertilizer treatment and the unfertilized control after 26 years (Fischer et al. 2005).

In a long-term fertilization trial in Darmstadt, Germany, plant-available Zn contents (measured using $CaCl_2$/DTPA extraction) of the very sandy soil were significantly higher after 24 years of cattle-manure compost fertilization than with mineral fertilization, while Mn and Cu contents did not differ between the treatments (Fischer et al. 2005).

With increasing rates of biowaste compost (5–20 t ha^{-1} dry wt.) applied to mostly silty loam soils in Baden-Württemberg, Germany, with a maize–winter wheat–winter barley rotation for 5 and 8 years, mobile Cu concentrations in soil (measured using NH_4NO_3 as extractant) increased slightly and Cu contents of crop products showed a slightly increasing trend. Mobile Zn concentrations in soil (in NH_4NO_3 extract) decreased slightly with increasing compost rates, while Zn contents of crop products were largely unaffected (Timmermann et al. 2003).

Similar trends were reported from a field experiment in Austria where 9.5–25.5 t ha^{-1} $year^{-1}$ (wet wt.) of biowaste compost were applied for 10 years to a calcareous Molli-gleyic Fluvisol and compared to mineral and no fertilization. Cu and Zn concentrations measured in soil saturation extract did not differ between the fertilization treatments. Cu concentrations in the potentially bioavailable fraction (measured in LiCl extract) were higher in the medium and high compost treatments than in the unfertilized control (Erhart et al. 2008). As total Cu concentrations in the compost treatments were only slightly, not significantly, increased, this was attributed to the higher soil organic matter concentrations and microbial activity in the compost treatments. Plant Cu uptake was higher with compost fertilization than with no fertilization, even though not in all crops. All Cu concentrations in crops were in the normal range reported in the literature or below that (Bartl et al. 2002). Total soil Zn concentrations were increased with high application rates of compost. In the LiCl extract, Zn was not detectable. Plant-uptake data showed increased Zn concentrations in compost-fertilized oat grains, while spelt and potatoes did not differ from the unfertilized control (Bartl et al. 2002). Manganese uptake by plants was lower with compost fertilization in oats, and about the same in spelt and potatoes. Molybdenum uptake by plants was increased in compost-fertilized spelt and unaffected in oats and potatoes (Bartl et al. 1999).

When 30 and 60 t ha^{-1} (wet wt.) of compost made from cotton wastes, sewage sludge, and olive-mill waste water (whose chemical characteristics and micronutrient content, however, were similar to those of biowaste compost) were applied to a calcareous, sandy clay loam textured soil in Spain, the Fe and Mn contents in the chard (*Beta vulgaris*) plants grown were higher than in the control which received mineral fertilizer. Cu and Zn contents in chard were unaffected by treatment.

The micronutrient contents of salad and barley, which were grown after chard, were only slightly affected (Cegarra et al. 1996).

In conclusion, with the use of high-quality compost (EU regulation 2092/91), only minor changes in the available micronutrient status of the soil are to be expected. As for crop plants, different species show varying micronutrient-uptake/exclusion patterns and micronutrients are not distributed uniformly between plant roots, stem, leaves, and fruits.

11.2.7 Soil Structure

In agronomic terms, a “good” soil structure is one which shows the following attributes: optimal soil strength and aggregate stability, which offer resistance to structural degradation (capping/crusting, slaking, and erosion, for example); optimal bulk density, which aids root development and contributes to other soil physical parameters such as water and air movement within the soil; optimal water-holding capacity and rate of water infiltration (Shepherd et al. 2002). Crops yield better in well-structured soils: Körschens et al. (1998) suggest a 5–10% benefit of good structure. Of course, root restriction may not necessarily penalize crop productivity, but it will do so if the supply of water and nutrients is inadequate (Shepherd et al. 2002). This is particularly important in organic farming, where deficits in soil structure may not be compensated by mineral fertilization.

It is not the optimum soil structure per se, which is decisive, however, but rather the ability of the soil to withstand structural degradation by the impact of rain, termed aggregate stability (Sekera and Brunner 1943). Increased aggregate stability protects the soil from compaction and erosion. Decreased bulk density and higher porosity improve soil aeration and drainage.

Increasing soil organic matter exerts a substantial influence on soil structure, particularly if – as in the case of compost application – CaO is supplied to the soil at the same time (Martins and Kowald 1988), improving soil physical characteristics like aggregate stability, bulk density, porosity, available water capacity, and infiltration (Giusquiani et al. 1995, Kahle and Belau 1998, Khalilian et al. 2002). To a remarkable degree, increased organic matter can counteract the ill effects of too much clay or too much sand (Weil and Magdoff 2004).

11.2.7.1 Aggregate Stability

As shown by Tisdall and Oades (1982), the water stability of aggregates depends on organic materials. The organic binding agents have been classified into (a) transient, mainly polysaccharides; (b) temporary, roots and fungal hyphae; and (c) persistent, resistant aromatic components associated with polyvalent metal cations, and strongly sorbed polymers. Roots and hyphae stabilize macro-aggregates, defined as >250 μm in diameter. Consequently, macroaggregation is controlled by soil management, as crop rotation, cover crops, mulches, organic fertilization, and tillage practices influence the growth of plant roots and the oxidation of organic carbon. The water stability of microaggregates (<250 μm in diameter) depends on the persistent organic binding agents, organomineral complexes, and humic acids (Chaney and Swift 1986), and appears to be a characteristic of the soil, independent of management (Tisdall and Oades 1982).

Increasing the soil organic matter content usually increases aggregate stability. Within a limited range of soil organic matter contents, the relationship for a given soil is nearly linear. However, across a wider range of soil organic matter, the relationship between these two variables is likely to be curvilinear, because at very high levels of soil organic matter, additional organic matter has little further effect on soil aggregation (Haynes 2000).

Addition of easily degradable organic material such as green manures leads to a rapid, but short-lived rise in aggregate stability. Addition of compost, in contrast, causes a slow, but long-standing increase in aggregate stability as its organic matter mainly consists of humic substances, which constitute relatively stable binding agents (Haynes and Naidu 1998). Therefore, a combination of green manures and compost application is optimal, because it combines the advantages of both.

Compost application usually influences aggregate stability immediately after a relatively short time (less than 3 years; (Asche et al. 1994; Kahle and Belau 1998; Steffens et al. 1996). With continued compost application, the effect continues also on the longer term (Ebertseder 1997; Martins and Kowald 1988, Petersen and Stöppler-Zimmer 1999; Sahin 1989; Siegrist et al. 1998; Timmermann et al. 2003). Soil bulk density decreases with compost application, although that takes longer than improving aggregate stability (Ebertseder 1997; Lynch et al. 2005; Timmermann et al. 2003).

The maturity of the compost used may impact its effect on aggregate stability. In an agricultural field experiment on loamy silt loess soil situated near Kassel, Germany, mature composts, which had been processed for 3 months had a greater effect on aggregate stability than immature composts, which had been processed for only 12–25 days (Petersen and Stöppler-Zimmer 1999). Heavy silt and clay soils benefit most from improved aggregate stability through compost application (Timmermann et al. 2003).

11.2.7.2 Porosity

Also soil pore volume typically increases with compost application. The proportion of large, continuous vertical coarse pores (>50 μm) is decisive for soil aeration and warming, and thus for root growth, and for soil water infiltration. Soil friability is improved with increasing pore volume of large and medium pores (Wegener and Moll 1997). In the subsoil, the proportion of large, continuous pores correlates with earthworm abundance (Poier and Richter 1992).

The increase in pore volume with compost application was found to be due to a rise in the proportion of coarse pores (Ebertseder 1997; Giusquiani et al. 1995; Martins and Kowald 1988; Sahin 1989) or in the proportion of medium and coarse pores, respectively (Steffens et al. 1996). Giusquiani et al. (1995) reported the greater porosity in the compost-treated plots to be due to an increase in the amount of elongated pores, which are considered most important both in soil–water–plant relationships and in maintaining good soil structure conditions.

11.2.7.3 Soil Water Availability

The water regime in soils is influenced by soil organic matter in several ways. First, organic matter increases the soil's capacity to hold plant-available water, defined as the difference between the water content at field capacity and that held at the permanent wilting point. It does so both by direct absorption of water and by enhancing the formation and stabilization of aggregates containing an abundance of pores that hold water under moderate tensions (Weil and Magdoff 2004). Hudson (1994) assessed the effect of the soil organic-matter content on the available water content of surface soils of three textural groups. Within each group, as organic matter increased, the volume of water held at field capacity increased at a much greater rate than that held at the permanent wilting point. As a result, highly significant positive correlations were found between organic-matter content and available water capacity. As organic-matter content increased from 0.5% to 3%, the available water capacity of the soil more than doubled (Hudson 1994).

An increase in soil water-holding capacity was observed in many studies with compost use, though it appears to take some time to come into effect. Evanylo and Sherony (2002), for example, did not find an increase in soil water-holding capacity after 2 years of compost application, and the effect was not very pronounced in other short-term trials (Avnimelech and Cohen 1993; Kahle and Belau 1998). In longer compost trials on the contrary, clear increases in water-holding capacity were reported (Giusquiani et al. 1995) (Fig. 11.2).

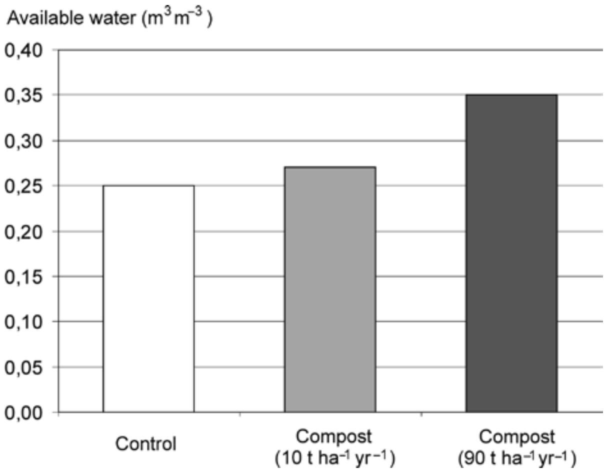

Fig. 11.2 Effects of compost addition on the available water in the surface layer; means of four replications. The linear term of regression (physical parameters : compost rates was significant at $P \leq 0.01$ (Drawn from data from Giusquiani et al. 1995)

Changes in the soil water regime may also be documented by measuring the soil water content, although this is more difficult because soil water content is also influenced significantly by crop water uptake. Zauner and Stahr (1997) and Lynch et al. (2005) observed higher soil water contents with compost fertilization, while Gagnon et al. (1998) found differences only in summer and only on a sandy loam, not on clayey soil.

Increased available water capacity may protect crops against drought stress. In dryland farming systems, where moisture is normally the most yield-limiting factor, improving soil moisture retention is an important nonnutrient benefit of compost application, which may exceed nutrient benefits (Stukenholtz et al. 2002).

11.2.7.4 Soil Water Infiltration

However, as important as the provision of ample water for plant growth is the capacity of the soil to absorb water as it impacts from rain or irrigation. When, because of structural properties at the soil surface, the rate of water infiltration into the soil surface is lower than the rate of rainfall, a portion of the rain is lost as surface runoff. The effect on the supply of water available for plants growing in that soil is similar to a significant reduction in rainfall (Weil and Magdoff 2004).

Improved soil structure through compost application increases soil water infiltration (Ebertseder 1997), although this also seems to take some time, as the small effects reported from short-term experiments show (Evanylo and Sherony 2002).

There is a close connection between soil infiltration and floods. Increased infiltration cannot influence the number of heavy rain events, but arguably their consequences. As agriculture occupies large areas, it may be supposed that even small changes in soil infiltration rate have significant effects on the number and magnitude of floods (Schnug and Haneklaus 2002).

11.2.8 Plant-Disease Suppression

There are numerous reports of composts suppressing plant diseases caused by *Pythium*, *Phytophthora*, *Rhizoctonia*, *Fusarium*, and *Aphanomyces* spp. and *Sclerotinia sclerotiorum* in growing media (Bruns and Schüler 2002; Erhart and Burian 1997; Hoitink and Fahy 1986; Hoitink et al. 2001; Lievens et al. 2001). Today composts are recognized to be as effective as fungicides for the control of root rots such as *Phytophthora* and *Pythium*. In some cases composts have successfully replaced methyl bromide in the US ornamental plant industry (Hoitink et al. 2001). Plant protection through composts is of particular importance in cultivation systems where the use of fungicides is impossible or not allowed, as in organic production or in production of potted herbs for fresh home consumption (Fuchs 2002; Raviv et al. 1998).

Disease control with compost is attributed to four factors: competition between beneficial organisms and the pathogen, antibiosis, parasitism, and induced systemic resistance. Two classes of biological control mechanisms known as "general" and "specific" suppression have been described for compost-amended substrates (Hoitink et al. 2001). The "general suppression" phenomen is related to the total amount of microbiological activity in composts and is known to suppress pathogens such as *Pythium* and *Phytophthora* spp. The second type of suppression, elicited by a specialist group of microorganisms capable of eradicating a certain pathogen, such as *Rhizoctonia solani*, is referred to as "specific" suppression.

The most critical factors for plant-disease suppression are the colonialization of the compost by an appropriate microflora and the decomposition level of the organic fraction in composts (maturity/stability), which affects biological control through supporting adequate activity of biocontrol agents (Hoitink and Boehm 1999). As shown by Stone (2002), the same processes involving active organic matter are likely at work in field systems.

High-rate, single-term amendments of organic matter can generate disease suppression in the first season after amendment. When composted dairy manure solids were applied at 28 and 56 t ha^{-1} (dry wt.), they reduced the severity of *Pythium* damping-off of cucumber by 30%, of bean root rot by 29% and of corn root rot by 67% 2 months after amendment (Darby et al. 2006). Such high amendment rates, however, cannot be applied year after year for environmental and economic reasons.

Field studies that assess low-rate single-season organic matter amendments report highly variable impacts on disease incidence and yield (Lewis et al. 1992; Lumsden et al. 1983), whereas longer-term studies report more predictable improvements in yield, quality, and disease suppression (Daamen et al. 1989; Workneh et al. 1993).

11.3 Potential Risks Associated with Compost Use

11.3.1 Heavy Metals

The accumulation of heavy metals in soils and crop plants is the most often cited potential risk of compost application. Heavy metal contents in composts vary widely dependent on compost feedstocks. For organic household and yard wastes, source separation, as introduced in Europe, proved to be effective in largely reducing compost heavy metal contents.

In organic farming, there are strict heavy metal limits for biowaste composts to be used. Composts from source-separated household waste must be produced in a closed and monitored collection system and must not exceed the following heavy metal limits (in mg/kg dry matter): Cd 0.7, Cu 70, Ni 25, Pb 45, Zn 200, Hg 0.4, Cr_{tot} 70, Cr (VI) 0 (EU regulation 2092/91).

Key interactive processes in the soil system affecting the partitioning of trace metals between the aqueous, bioavailable, and the solid phase include precipitation, ion exchange, adsorption onto organic matter, oxides and allophanes, and absorption into biological material. The major factors driving the biogeochemical processes in soils are pH, cation exchange capacity. and redox potential. Soil microorganisms interact with trace metals in various ways which may render them more or less bioavailable. Crops differ considerably not only in their general sensitivity to trace elements, but also in their relative sensitivity to individual trace elements. The uptake of trace elements may vary considerably among cultivars; and within the plant, trace elements are not uniformly distributed among plant tissues (Adriano 1986).

The results of field experiments show that with the use of high-quality biowaste composts, increases in soil heavy metal concentrations are not measurable in the shorter term.

In the experiments of Kluge and Mokry (2000), 7–9 t ha^{-1} (dry wt.), compost from biowaste and green waste per year were applied for 3 years to six different agricultural sites. The soil total heavy metal concentrations were unaffected by the compost fertilization. In the mobile heavy metal concentrations (measured using NH_4NO_3 as extractant) even a decrease was reported (Kluge and Mokry 2000).

Strumpf et al. (2004) applied 20 and 50 t ha^{-1} (dry wt.) biowaste compost of urban origin in a single dose to an experimental field, where 12 vegetable species were grown in the following 3 years. Soil total heavy metal concentrations were not affected by the compost application. No difference was found in the heavy metal concentrations of the soil solution (extracted by suction cups) between the compost treatments and the untreated control. Also the heavy metal concentrations in the vegetables grown in the experiment did not differ between the treatments.

In the experiment of Oehmichen et al. (1994), 4–24 t ha^{-1} compost was applied annually to agricultural crop rotations on two experimental sites for 3 years. Soil heavy metal concentrations at the end of the experiment were not significantly different from the unfertilized control.

No increases in total soil heavy metal concentrations were measurable after 10 experimental years with total applications of 95, 175, and 255 t biowaste compost (wet wt.) ha^{-1}, respectively, to a Molli-gleyic Fluvisol cropped with cereals and potatoes, except for Zn in the treatments with the highest application rate. In the mobile heavy metal fractions measured in soil saturation extract and LiCl extract, no significant increases were detected except for Cu in LiCl extract (Erhart et al. 2008). Plant heavy metal uptake data showed no significant differences in Ni uptake between the fertilization treatments. Pb was not detectable in crops. Cd concentrations in grains of oat and spelt and potato tubers were significantly lower with compost fertilization than with no fertilization. In the potatoes which had received mineral fertilizer, significantly higher Cd concentrations were found, most probably due to the Cd input via superphosphate and triple superphosphate fertilizer (Bartl et al. 2002) (Fig. 11.3). The total Cd loads imported via phosphorus fertilization appear small, but they are much more likely available to biota than the Cd bound in the soil (Sager 1997).

It might be concluded, that with the use of high-quality composts, such as specified by the EU regulation 2092/91, the risk of heavy metal accumulation in the soil is very low. As compost application usually leads to a rise in soil organic matter and, with that, improves the sorption capacity of soils, mobile heavy metal fractions in most cases remain the same or even decrease with compost use.

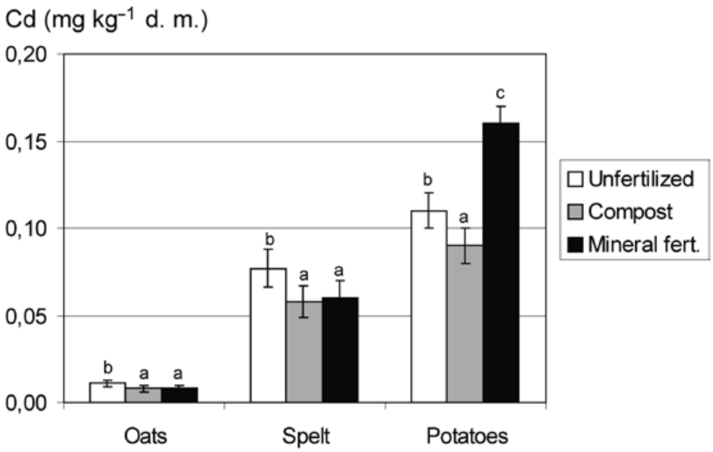

Fig. 11.3 Cd contents (mg kg^{-1} d.m.) in crops fertilized with biowaste compost at 32 t (wet wt.) ha^{-1} year^{-1} for 7 years, as compared to mineral fertilization (71 kg N, 19 kg P, and 68 kg K ha^{-1} year^{-1}) and to no fertilization. Treatments with the *same letters* are not significantly different at $P \leq 0.05$ (Drawn from data from Bartl et al. 2002)

11.3.2 Organic Compounds

In high-quality biowaste composts, the contents of organic pollutants such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), or polychlorinated dibenzodioxins and dibenzofurans (PCDD/F) and other compounds are low due to the separate collection of the compost feedstock (Brändli et al. 2007a, b; Timmermann et al. 2003; Zethner et al. 2000). Investigations of pesticide residues in compost detected few of the target pesticides. The compounds that were found occurred at low concentrations (Büyüksönmez et al. 2000). The composting process contributes to the degradation of organic compounds by the heat generated and by microbiological and biochemical oxidative processes (Amlinger et al. 2006).

The application of compost to the soil may have varying effects concerning organic pollutants. Due to their high organic-matter content, composts may bind pollutants and thus lower their availability and toxicity. The increased activity of the soil microflora provides improved conditions for biological (oxidative) degradation of pollutants (Amlinger et al. 2006).

Accumulation scenarios of persistent pollutants (PAHs, PCBs, PCDD/F) show that, assuming realistic half-lives in soil, the average input through deposition and compost will not lead to an accumulation in soil (except a slight increase in PAHs in the case of very low soil background values). The input is more than offset by natural degradation (Amlinger et al. 2004). The absence of changes in the soil concentrations of PCBs and PCDD/F was confirmed by measurements in field experiments in Germany (Timmermann et al. 2003).

The pollutant loads are so small, that even with overly high compost rates no measurable increase in soil contents may be expected (Amlinger et al. 2006).

11.3.3 Hygiene, Plant Diseases, Weeds

Most plant pathogens are inactivated during proper aerobic composting. For bacterial plant pathogens and nematodes, the majority of fungal plant pathogens, and a number of plant viruses, a compost temperature of 55°C for 21 days is sufficient for ensuring eradication. For *Plasmodiophora brassicae*, the causal agent of clubroot of *Brassicas*, and *Fusarium oxysporum* f. sp. *lycopersici*, the causal agent of tomato wilt, a compost temperature of at least 65°C for up to 21 days is required for eradication. Several plant viruses, particularly Tobacco Mosaic Virus (TMV) are temperature-tolerant. However, there is evidence that TMV and Tomato Mosaic Virus are degraded over time in compost, even at temperatures below 50°C (Noble and Roberts 2003; Termorshuizen et al. 2005).

Timmermann et al. (2003) found in their examination of numerous composts for the RAL-GZ quality control, that the overall hygiene (e.g., concerning *E. coli*) and hygiene concerning plant diseases of biowaste composts was always warranted, if sufficiently high temperatures (65°C) were attained during at least 7 days in the composting process. The same was true for viable weed seeds and plant parts in the composts. As their analyses showed, quality composts were virtually free of viable weed seeds and plant parts.

In the field experiments in Baden-Württemberg, weed ratings were conducted routinely (at a total of 42 experiment years) and the occurrence of weeds was found to be not increased with biowaste-compost use (Timmermann et al. 2003).

11.4 Crop Yields and Quality with Compost Use

11.4.1 Agricultural Crops

The total of all effects of compost use is reflected best in crop yields. The effect of compost fertilization on crop yields depends on the factors determining nutrient mineralization from soil and compost, but also on crop-related factors such as the nutrient requirements and uptake dynamics of the respective crop.

11.4.1.1 Cereals

With cereals, a wide range of yield responses to compost fertilization has been recorded. Nonsignificant wheat yield increases followed the application of 6.9 t ha^{-1} (dry wt.) biowaste compost on a parabrown soil in Germany (von Fragstein and Schmidt 1999). Also in the experiment of Oehmichen et al. (1995), small and only partly significant yield increases were found. In a trial in Southeast England, however, with municipal solid-waste compost at 50 and 100 t ha^{-1} (wet wt.) on a loamy clay soil, compost-treated plots produced grain yields comparable to those which received 75 or 150 kg ha^{-1} mineral N fertilizer (Rodrigues et al. 1996). On a Gray Luvisolic soil with low inherent soil fertility and relatively poor soil structure in Alberta, Canada, municipal solid-waste compost was applied at rates of 50, 100, and 200 t ha^{-1} (wet wt.). Wheat yields were 170% and barley yields were 270% of the untreated control in the 50 t ha^{-1} treatment (Zhang et al. 2000).

In the DOK experiment in Switzerland, winter wheat yields with manure-compost fertilization in organic farming reached 90% of the grain harvest of the conventional system in the third crop rotation period (Mäder et al. 2002).

In a 3-year field experiment on a podsolic soil in Germany, rye yield increased for 5–12%, when 30 and 60 m^3 ha^{-1} (corresponding to approx. 20 and 40 t ha^{-1} wet wt.) yard-trimmings compost were applied annually (Klasink and Steffens 1996). Oehmichen et al. (1995) reported rye yield increases in the range of 9–15% after annual application of 6–18 t compost (wet wt.) ha^{-1} on a Luvisol.

While barley yields were significantly higher than the control with 4.1 t ha^{-1} (dry wt.) biowaste compost on a parabrown soil in Germany (von Fragstein and Schmidt 1999), 150 t ha^{-1} (wet wt.) of garden-waste compost was necessary to give significantly higher barley yields on a sandy loam soil in Britain (Cook et al. 1998).

In five field experiments in Baden-Württemberg, Germany, with a duration of 5–8 years and a maize–winter wheat–winter barley rotation, average yield increases between 11% and 28% were recorded with biowaste-compost fertilization at 5, 10, and 20 t ha^{-1} (dry wt.) as compared to the unfertilized control (Timmermann et al. 2003) (Fig. 11.4).

With application of 9–23 t ha^{-1} year^{-1} (wet wt.) biowaste compost, yields of cereals and potatoes increased for 7–10% compared to the unfertilized control (average of 10 years). On a fertile Fluvisol under relatively dry climatic conditions, the yield

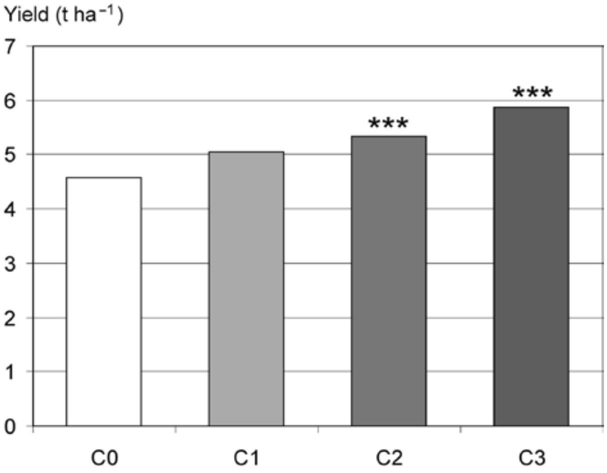

Fig. 11.4 Average yields 1995–2002 of five field experiments with a maize–wheat–barley rotation with biowaste-compost fertilization at 5 t ha^{-1} year^{-1} (dry wt.) = C1, 10 t ha^{-1} year^{-1} = C2, and 20 t ha^{-1} year^{-1} = C3 as compared to no fertilization = C0. Stars indicate statistically significant differences at $P \leq 0.01$ (Drawn from data from Timmermann et al. 2003)

response to the compost applications was very low in the beginning and increased slightly with the duration of the experiment (Erhart et al. 2005).

11.4.1.2 Potatoes

Little influence of compost application (at 43 and 86 t (wet wt.) ha^{-1}, respectively) on potato tuber production was recorded by Volterrani et al. (1996) on a sandy soil in Italy. In the experiment of Klasink and Steffens (1996), potato yield increased for maximally 4%. In the DOK experiment in Switzerland, potato yields with manure-compost fertilization in organic farming were 40% lower than in the conventional system mainly due to low potassium supply and the incidence of *Phytophthora infestans* (Mäder et al. 2002).

In an experiment of Vogtmann et al. (1993b), 80, 20, and 50 t ha^{-1} (wet wt.) biowaste compost had been applied in subsequent years to a silty loam Luvisol. The potato yield in the compost treatment was significantly higher than in the control, and comparable to that produced with 200 kg N ha^{-1} mineral fertilizer.

11.4.1.3 Maize

Maize has a very high N requirement, and also a longer growth period than cereals. On a shaly silt loam in Pennsylvania, dairy manure leaf compost was applied at 27 t ha^{-1} (dry wt.) annually for 3 years. In the first year, maize yields were significantly lower than with mineral fertilization at 146 kg N ha^{-1}, but in the second and third year they were not significantly different (Reider et al. 2000). Parkinson et al. (1999) applied green-waste compost at 15, 30, and 50 t ha^{-1} (wet wt.) on a silty loam soil in South West England. There was a positive yield response of 1–18% to the application of compost in each of the 3 years.

In a field experiment at Wye, Britain, manure compost at 25 and 50 t ha^{-1} was compared with inorganic N fertilizer at 50 and 100 kg N ha^{-1} using two forage maize varieties. While the fresh yield of the late-maturing variety was higher, the yield of the early maturing variety was only about equivalent to that with inorganic fertilizer, showing the positive influence of a longer growth period on the N uptake from compost (De Toledo et al. 1996).

11.4.2 Vegetable Crops

In vegetable production, intensive soil cultivation promotes rapid mineralization of soil organic matter, which may lead to a gradual loss of soil fertility. Most vegetable crops need a soil that is rich in organic matter, well-structured, and with a high water-holding capacity. Therefore many vegetable crops, particularly the highly nutrient-demanding ones, respond favorably to compost fertilization, often already after the first application. Supplying the total N requirements of vegetables with compost is possible, as several experiments have shown, but as N mineralization from compost is often as low as 5–15% of total N, large amounts of compost are required. In order to achieve high yields, but avoid a buildup of nutrient concentrations in the soil through excessive compost rates, compost could be combined with either legumes or organic fertilizers in which N is more readily available.

11.4.2.1 Solanaceous Crops

For the solanaceous crops, tomatoes (*Lycopersicon esculentum*), peppers (*Capsicum annuum*), and eggplant (*Solanum melongena*), equal to significantly greater yields with compost compared with mineral fertilizer, were reported. For example, in a 3-year trial on two sites (one with sandy soil, one with loamy soil), in which fertilization with chicken-manure compost at 56 and 112 t ha^{-1}, respectively, was compared to mineral fertilization at 146N-64P-121K (kg ha^{-1}; Maynard 1994), and in an experiment with sugarcane filtercake compost at 224 t ha^{-1}, compared to mineral fertilizer at up to 153 kg N ha^{-1} on a fine sand soil (Stoffella and Graetz 1996).

When a processing tomato–proteic pea–rotation on a silty clay soil in southern Italy was fertilized for 4 years with 7.1 t ha^{-1} (dry wt.) compost from olive mill residues, sludge, straw, and orange wastes, tomato yields did not differ significantly from those in the treatment receiving 100 kg N ha^{-1} as ammonium nitrate (Rinaldi et al. 2007).

11.4.2.2 Cruciferous Crops

In the cruciferous crops broccoli, cauliflower (*Brassica oleracea convar. botrytis var. italica*, and var. *botrytis*, respectively), kohlrabi (*B. oleracea convar. caulorapa var. gongylodes*), and cabbage (*B. oleracea convar. capitata*), improved crop responses with compost fertilization compared to fertilizer-only treatments were recorded, provided crop nutrient demands were satisfied. For example in a study by Roe and Cornforth (1997), who used dairy manure compost at rates of 22, 45, and 90 t ha^{-1} plus mineral fertilizer at 112 kg ha^{-1} N to grow autumn broccoli. Broccoli yields were up to twice as high as with mineral fertilizer alone. When biowaste compost was applied at 60 t ha^{-1} (dry wt.) to kohlrabi, yields were similar to those with 70 kg ha^{-1} N as mineral fertilizer (Vogtmann and Fricke 1989).

In the chicken-manure compost experiment by Maynard (1994) described above, yield of broccoli and cauliflower from the compost plots equaled the fertilized control at both sites in all 3 years with two exceptions (one higher, one lower). In another experiment with leaf compost at 56 and 112 t ha^{-1} plus fertilizer at 0, 73N-32P-61K,and 146N-64P-121K (kg ha^{-1}), respectively, broccoli and cauliflower did not obtain optimum yields on the reduced fertilizer plots until the second and third years (Maynard 2000).

11.4.2.3 Cucurbitaceae

When cantaloupe (*Cucumis melo*) was grown with manure compost at 22, 45, and 90 t ha^{-1}, respectively, plus 23N-14P (kg ha^{-1}), cantaloupe yields were up to three times as high as with mineral fertilization only (Roe and Cornforth 1997).

11.4.2.4 Legumes

The response of legumes to compost may differ from that of other crops due to their ability to fix N, but nevertheless they may profit from nutrients other than N and from improved soil conditions. Snap bean (*Phaseolus vulgaris*) seedling emergence and plant survival were increased by the addition of 2.5 cm of leaf compost as a mulch over rows after seeding. Pod yields were equal to significantly higher with compost mulch (Gray and Tawhid, 1995). Baziramakenga and Simard (2001) used a paper residues/poultry-manure compost at 0, 14, 28, and 42 t ha^{-1} (dry wt.), supplemented or not with mineral fertilizer at 0, 60, 120, and 180 kg P_2O_5-K_2O ha^{-1}. Snap bean yields in the compost treatments increased significantly compared with the untreated control and were similar to those in the mineral-fertilizer treatments.

11.4.2.5 Onions

In a 3-year trial with four cultivars of onions (*Allium cepa*) annual applications of 112 t ha^{-1} leaf compost plus 146N-66P-121K (kg ha^{-1}) were compared to mineral fertilization only (Maynard and Hill 2000). After 3 years of compost additions, yields of the three Spanish onion cultivars from the compost plots were significantly greater than from unamended plots. Year-to-year variability in yields in response to variable rainfall was significantly lower and percentage of colossal and jumbo-sized onions was greater in compost-amended plots. Repeated compost additions also reduced the incidence of soft rot disease.

11.4.3 Crop Quality

The crop quality of cereals is usually not affected by compost fertilization (Cook et al. 1998, Erhart et al. 2005, von Fragstein and Schmidt 1999, Oehmichen et al. 1995). In potatoes and cabbage, lower concentrations of nitrate and free amino acids with compost than with mineral fertilization were observed (Vogtmann et al. 1993b, Roinila et al. 2003; Erhart et al. 2005). Those lower nitrate concentrations in vegetables are supposedly due not only to lower soil nitrate levels in the compost plots, but also to the slow-release nature of compost. In tomatoes, compost fertilization was reported to yield higher titratable acidity values, higher electrical conductivity

(E.C.), and a somewhat superior sensory quality (Madrid et al. 1998, Vogtmann et al. 1993b).

As a general trend, Vogtmann et al. (1993b) found compost to positively influence food quality, to improve storage performance of vegetables, and to yield a slightly better sensory quality.

11.5 Conclusion

Probably the most important benefit of using compost is the increase in soil organic matter. Numerous experiments show that compost fertilization regularly leads to a distinctive increase in the humus content of the soil. Moderate levels of compost application (around 6–7 t ha^{-1} $year^{-1}$ dry wt.) are usually sufficient for the maintenance of the soil humus level. Regular compost addition increases soil fauna and soil microbial biomass and stimulates enzyme activity, leading to increased mineralization of organic matter and improved resistance against pests and diseases, both features essential for organic farming. Composting permits to recycle leftover organic matter, which otherwise would be lost. Through the significant increase in the soil's content of organic carbon, compost fertilization may make agricultural soil a carbon sink and thus contribute to the mitigation of the greenhouse effect.

As phosphorus and potassium in compost become nearly completely plant-available within a few years after compost application, the total P and K content of composts can be accounted for in the fertilizer calculation. The nitrogen-fertilizer value of compost is lower. In the first years of compost application, N mineralization calculated from the results of field trials varied from −14% to +15%. Nitrogen recovery in the following years depends on the site- and cultivation-specific mineralization characteristics and will be roughly the same as that of soil organic matter. Moderate rates of compost are sufficient to substitute regular soil liming.

Increasing soil organic matter exerts a substantial influence on soil structure, improving soil physical characteristics like aggregate stability, bulk density, porosity, available water capacity, and infiltration. Increased aggregate stability protects the soil from compaction and erosion. Decreased bulk density and higher porosity improve soil aeration and drainage. Increased available water capacity may protect crops against drought stress. These effects gradually improve soil fertility. And they improve soil qualities such as soil workability, resistance to erosion, water-holding capacity and soil activity, which are essential for crop production particularly in organic farming, where deficits in soil structure may not be compensated by mineral fertilization. On the medium and long term the soil-improving effects of compost application have at least the same, if not a greater importance than its fertilizer effects.

When using high-quality composts, such as specified by the EU regulation 2092/91, the risk of heavy metal accumulation in the soil is very low. Nitrogen mineralization from compost takes place relatively slowly and there are virtually no reports of a sudden, ecologically problematic rise in soluble N pools and uncontrollable

N-leaching. Therefore, compost fertilization does not pose a risk of groundwater eutrophication.

Concentrations of persistent organic pollutants (PAHs, PCBs, PCDD/F) in high-quality composts usually approach the usual soil background values. Also the overall hygiene and hygiene concerning plant diseases and weeds is not a problem if quality composts produced in a monitored system are used.

Most studies found positive yield effects of biowaste compost. However, the effect of biowaste compost applied at moderate rates usually takes some years to develop. It depends on the factors determining nutrient mineralization from soil and compost, but also on crop-related factors such as the nutrient requirements and uptake dynamics of the respective crop rotation. Crops with longer growth periods can make better use of compost. Many vegetable crops respond favorably to compost fertilization, often already after the first application.

Crop quality is usually not affected by compost fertilization in cereals, and slightly positively influenced in vegetable crops.

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