1 Compost and soil ecosystem resilience in organic greenhouses

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In short:

- The use of compost in organic farming systems matches with the principles of ecology, and the efforts to reduce inputs by reuse and recycling of materials and energy.
- In order to enhance the level of resilience, including the self-regulating capacity of the farming system, management strategies should foster high levels of biodiversity.
- The application of compost can support soil ecosystem resilience by enhancing organic matter storage and transformation, nutrient storage and mineralization, and by improving aggregate stability leading to improved soil structure, water transport, water holding capacity and disease suppressiveness.
- In order to decide the type and amount of organic amendment, a soil assessment can be helpful to identify the areas in which the soil, soil organisms and crops should be supported most.

1.1 Introduction

According to the International Federation of Organic Agriculture Movements (IFOAM), organic farming is "a production system which sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects"[1]. Organic agriculture is a whole systems approach (Figure 1.2), which involves understanding and supporting processes that contribute to the four principles of health, ecology, fairness and care. The organic production system is more than a system that is just concerned with including or excluding certain types of inputs. One of the four principles of organic farming is the principle of ecology. Because it is rooted in ecological systems, "organic production is to be based on ecological processes, and recycling (...). Inputs should be reduced by reuse, recycling and efficient management of materials and energy in order to maintain and improve environmental quality and conserve resources"[1]. Compost, as a product of recycling processes, can be a very appropriate input material for organic farming, provided the composting process is well-managed, the input materials are free of contaminants, and the resulting product is applied according to the system's ecological needs.

Figure 1.1 *Organic greenhouse production systems can vary greatly in intensity. Left: intensively managed organic greenhouse, with crop rotation of tomato, sweet pepper and cucumber. Right: extensively managed greenhouse, with leafy vegetables in winter, heated only to keep the greenhouse frost-free.*

Compost is a very important input material for organic greenhouse production. Organic greenhouse production may vary in the level of intensity (Figure 1.1), but it is generally a system with high turnover rates of organic matter, high inputs of both nutrients and energy, and high production levels. Compost is used as an important source of organic matter and nutrients in greenhouse horticulture, and is an important component of growing media for nurseries. Compost plays an important role in building a resilient farming system, by providing both the energy sources and the nutrients to sustain soil biodiversity. This chapter highlights the most important soil functions, how they are mediated by soil organisms, and what it takes to make farming systems resilient. Nourishing these soil organisms through the use of compost , strengthens the ecosystem services that these organisms provide.

Figure 1.2 *Organic greenhouse production: a whole systems approach, including the four principles of health, ecology, fairness and care. Recognizing processes, cycles and interactions are important components of building organic production systems.*

1.2 Resilient farming systems

1.2.1 Resilience and biodiversity

The concept of resilience in ecology has been developed from the idea that organic systems are naturally and constantly changing. Organic systems are characterized by continuous changes caused by external factors as opposed to mechanical systems in which consistent behavior is desirable. Stability means that a system is able to stay very close to the equilibrium state after being disturbed. The more rapidly it returns, with the least fluctuation, the more stable it is. Resilience is something different. It can be defined by the ability of a system to undergo disturbance, but at the same time maintain its functions. By moving the focus from stability to resilience, we are not so much occupied by the maintenance of a fixed equilibrium state. The resilience view emphasizes the need to keep options open and to value heterogeneity, in order to deal with every kind of future event[2]. Resilience could be measured in three ways[3]:

- The amount of change a system can undergo, and still retain its controls on function and structure;
- The degree to which the system is capable of self-organization;
- The ability to build and increase the capacity for learning and adaptation.

The level of biodiversity of a system can make the difference between the amount of stress or resilience that the system will experience when a sudden change occurs. Biodiversity is needed in all agroecosystems to provide the required ecosystem functions[4]. Although a high biodiversity may not be critical under 'friendly' conditions, it might become important under changing circumstances. Biodiversity can be seen as a kind of insurance, or buffer, against environmental fluctuations. Species that are functionally ‘redundant’ at a certain point in time, may no longer be redundant when disturbances occur that destroy the species which carried out those functions earlier[5]. Some ecosystem functions are carried out by a large variety of species. One of the examples often mentioned is the decomposition of organic matter. Microbial redundancy may be relatively high in the decomposer community, coupled to a strong resilience. We are only just beginning to understand the complexity of soil decomposers, however, and different groups and species still have to be linked to rates and routes of soil organic matter processing[6]. It might be more appropriate to speak about ‘niche complementarity’[7] instead of redundancy. Other soil functions are carried out by only a few organisms, e.g. deep-burrowing earthworm species who act as ‘ecosystem engineers’. When they are dispelled by too intense tillage, their functions are not taken over by other organisms, resulting in reduced ‘niche complementarity’ and a weak resilience of this soil ecosystem function. It is necessary to deepen our knowledge of the functions of soil life, in order to develop a better understanding of how to support agroecosystem resilience. Soil organisms support the farmer in several ways[8]:

- Storage, transport and transformation of carbon sources;
- Storage, transport and transformation of nutrients;
- Storage and transport of water and air;
- Providing carrying capacity and resistance to compaction;
- Providing resistance to erosion and sealing;
- Regulation of other soil biota (including soil-borne diseases);
- Detoxification and filtration of contaminants;
- Regulation of atmospheric composition.

1.2.2 Farm management options: risk management or resilience

Farm management styles could be classified as being located somewhere on a spectrum of measures, that are oriented towards risk management and control at one extreme, and oriented towards resilience and adaptation at the other. Since the start of the Green Revolution, farming systems have gradually developed to be more and more oriented towards the risk management model. Production systems have been simplified not only in terms of crop rotation, but also regarding the amount of genetic variation in both major staple crops, and also in vegetables and fruit crops. Risks of nutrient and water shortages have been addressed by the increase in use of chemical fertilizers and irrigation in these systems, and pathogens and pests have been suppressed by the application of chemical pesticides. While reducing the short-term risks, this system involves a continuous high level of control and inputs (Figure 1.3, left). The ball (representing a system state) can only stay in place by external forces (the arrows) which keep it from moving away. The environment shows no resilience: without the external controls, any disturbance will cause the ball to roll downwards. The system involves high long-term risks: when the underlying system becomes too degraded, control measures will either become ineffective or very costly.

At the other side of the spectrum is the resilience or adaptation model of farm management. The measures which are taken support the underlying system. They are not so much concerned with a fixed equilibrium state, but with the broader environment. The ball may move away from its original position, the situation may not be stable, but it will be able to carry out all the functions (Figure 1.3, right). Management strategies that increase resilience tend to focus on a high level of biodiversity and a greater variability within the production system.

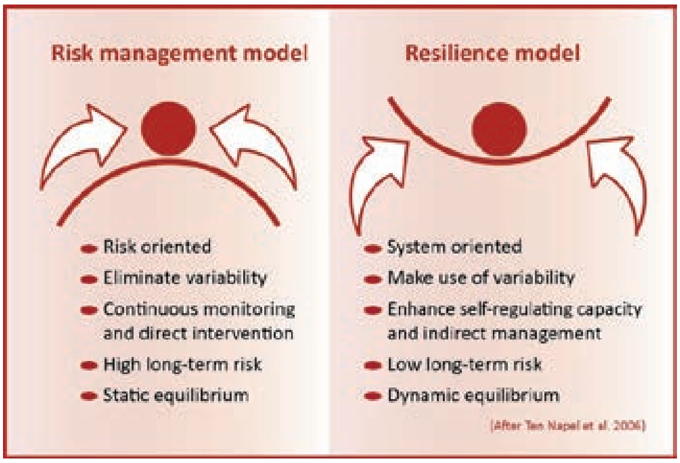

Figure 1.3 *General characteristics of systems based on risk management, or control models (left) and resilience, or adaptation models (right) (adapted from[9]).*

1.2.3 Resilience and risk management in organic greenhouse production

The resilience model plays a key role in organic farming systems. Organic agriculture is a whole-systems approach, which aims to enhance the self-regulating capacity of the ecological processes and which supports high levels of biodiversity (Figure 1.2). Managing an organic production system includes recognizing and supporting all the aspects and interactions which enhance the system's resilience. Management strategies in organic greenhouses are likewise based on supporting the entire ecological system. Management measures like crop rotation, rootstock selection, and the addition of sufficient amounts of high quality organic matter make the production system more resilient (Figure 1.4). But organic greenhouse production is also an intensive growing system. Crop rotation is generally narrowed down to those crops which are economically viable when cultivated under the roof of a high-value greenhouse construction. The growing season is lengthened by application of heating and cooling systems, requiring high levels of energy inputs. This increases production levels and turnover rates of organic matter and nutrients, demanding higher inputs of both organic matter and minerals. The farming system is also separated from the natural environment, making it dependent on the artificial introduction of pollinators and natural enemies of aphids and other pests.

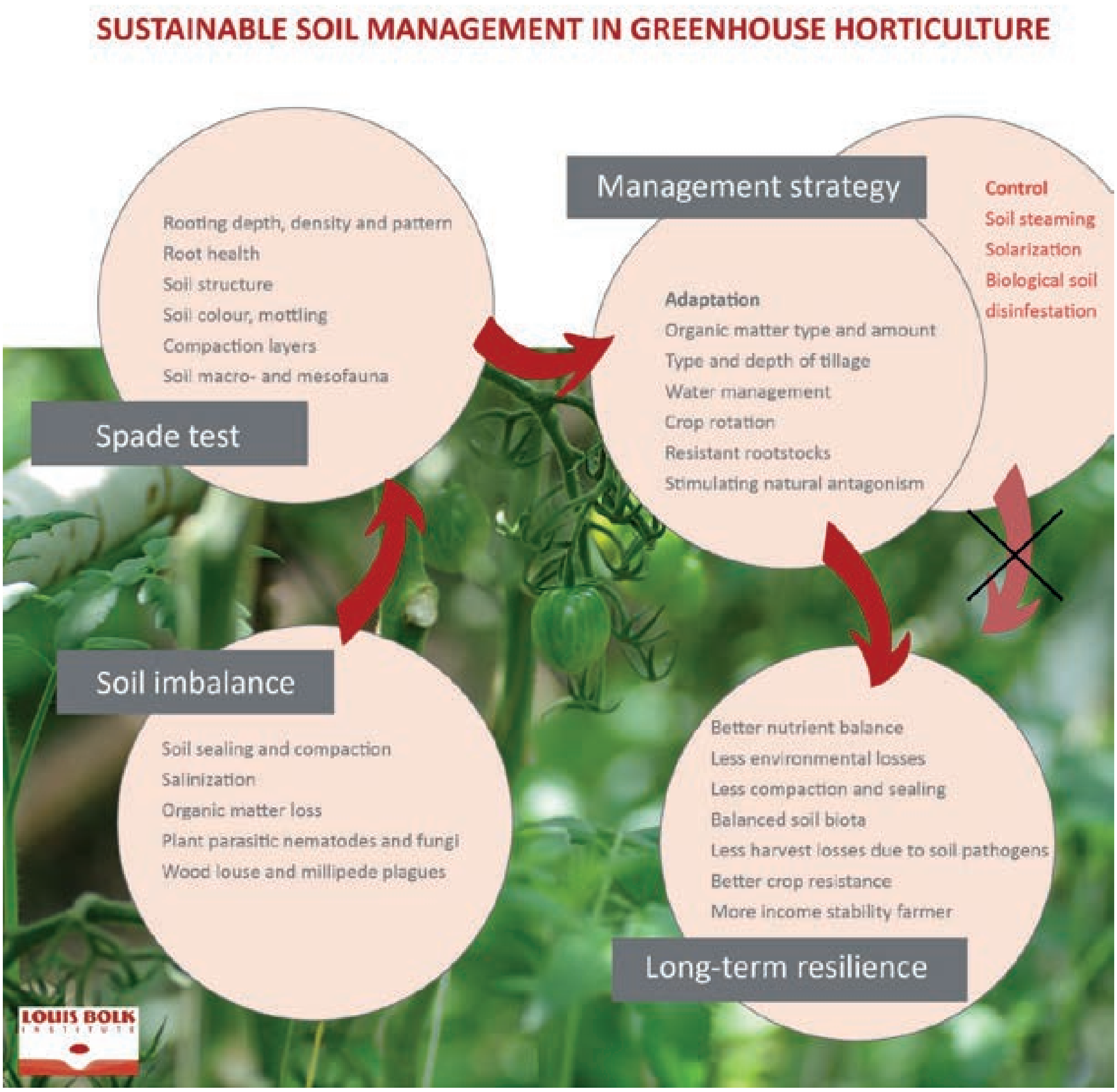

Figure 1.4 *Sustainable soil management in organic greenhouse horticulture. Some management strategies are oriented towards adaptation, resulting in a more resilient system. Other strategies are focussed on control measures, which provide short-term solutions, but do not improve long-term resilience.*

This makes organic greenhouse farming more risk oriented, and inclined towards management options based on control measures. Growers may even choose to use control measures like biological soil disinfestation, solarisation or soil steaming, when levels of soil-borne pathogens become so high, that severe production losses are likely. These measures reduce short-term risks, but the disturbances caused to soil biodiversity do not support long-time resilience.

In order to compensate for control measures which tend to decrease biodiversity and resilience, organic greenhouse growers apply a variety of strategies to support the natural capacity of the ecosystem to sustain production. High-quality compost is used to support soil biodiversity. Composts enriched with mycorrhiza or antagonistic fungi are applied in planting holes or at the nurseries. And although decomposition rates are low when compared to manure or side dressings, they form a strong source of nutrients over time due to the large amounts of compost applied. The next paragraphs will discuss the most important contributions which composts make to the various soil ecosystem functions.

Figure 1.5 *Management strategies in organic greenhouses involve sometimes control measures like soil steaming (left). Type, frequency and depth of tillage (right) can influence soil structure directly, but also indirectly by the effect on, for example, earthworms.*

1.3 Composts and soil ecosystem resilience

Composts contribute to soil ecosystem resilience by nourishing the soil organisms that mediate the different functions of soils. Many functions of soils have relationships with specific soil organisms which help to sustain those functions. Although it may seem that functions like carrying capacity and resistance against sealing mainly depend on the mineral and textural characteristics of soil, these functions can also be enhanced by the activity of macrofauna (e.g. earthworms) and microflora (e.g. fungi, bacteria and algae). The majority of these functions would quickly deteriorate without a living soil. This chapter highlights the contributions which composts may make to various ecosystem functions of soils. These are direct through the addition of organic matter and nutrients to soil and, more importantly, indirect through the feeding of the organisms which support ecosystem functioning. The following major functions will be addressed below:

- Organic matter storage and transformation;
- Storage, transport and mineralization;
- Soil structure, aggregate stability, water storage and transport.

A very important aspect of soil ecosystem functions is the regulation of other soil biota, including soil-borne diseases. As disease suppressiveness of soils will be discussed in detail in Chapter 6, we will not expand on the subject here.

1.3.1 Organic matter storage and transformation

The living soil is at the basis of organic farming systems. Primary plant production will ultimately decline without a well-functioning soil that is rich in biodiversity. This is seen in all parts of the European Union, where an estimated 52 million hectares (more than 16% of the total land area) of soil are prone to some kind of degradation process[10]. In the Mediterranean area, desertification forms a serious threat, and about 1/3rd of the Mediterranean agricultural area is suffering from land degradation. Degradation also takes place in the young and most fertile soils of the Netherlands through compaction and loss of organic matter, caused mainly by intensified cultivation, narrowed down crop rotations, and the use of heavy machinery[11].

The presence of organic matter is of primary importance to soil biodiversity, as it is the primary energy source for soil micro-organisms, thus catalyzing and supporting the entire soil food web. As soil bacteria, fungi and protozoa decompose soil organic matter, they release inorganic nutrients that are necessary for plant growth. As earthworms break down soil organic matter, their casts line soil aggregates, and hold them together, providing a more stable soil structure. Burrows of earthworms foster both aeration and water infiltration. In the absence of a continuous input of fresh organic matter in the soil, the level of activity and diversity of soil organisms will ultimately decline. This could lead to a reduction of functions that soil organisms are able to carry out, and consequently a loss of resilience. The aboveground diversity of crops also influences the ability of the belowground microflora to convert organic amendments. Field experiments have shown that soils of fields with complex crop rotations decompose crop residues more rapidly than soils of fields with monocultures[12].

The inherent amount of organic matter in a soil depends on both natural and human-induced factors. Important natural factors are climate and soil parent material. Decomposition rates of organic matter are a function of temperature and moisture content, and with every 10°C decrease in temperature, the average amount of organic matter increases with 2-3-fold[10]. Therefore, northern European soils naturally contain higher levels of organic matter than Mediterranean ones which typically contain up to 2% organic matter. Parent materials are also an important factor in the natural amount of organic matter available. Fluvisols on young, calcareous sea clay have strong mineralizing properties, which impede the increase in organic matter. More developed, and less calcareous, river clay soils have less strong mineralizing properties, and are able to develop higher organic matter contents over time[13].

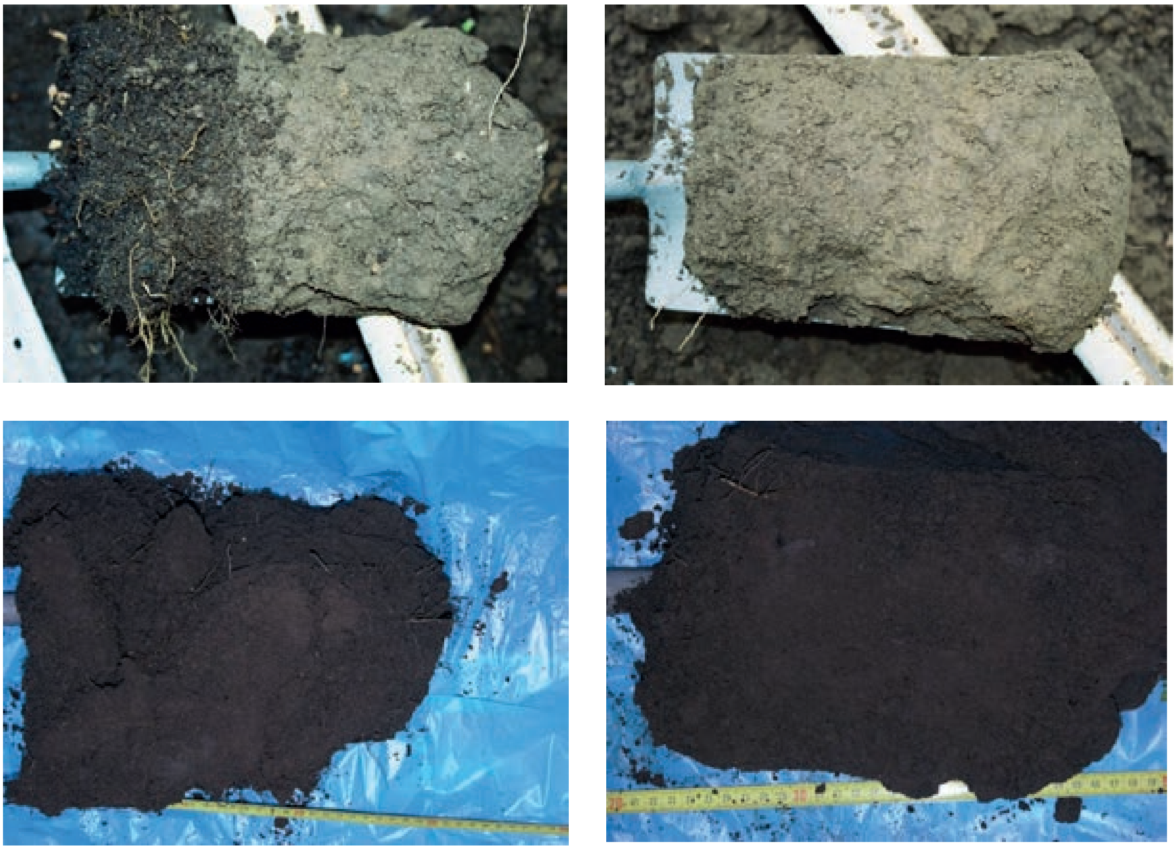

***Figure 1.6** Soil profile of a sandy soil under organic greenhouse management in 2002 (top) and 2005 (bottom). Left: top 22 cm, Right: lower 22 cm. In 2002 there is a sharp demarcation between the different soil layers: the organic matter is confined to the upper 8 cm of soil, as are most of the roots. In 2005, after 3 seasons of ample compost application, the organic matter is homogeneously distributed through both soil layers.*

Human-induced factors are strongly responsible for the general decline of organic matter in soils. In intensive greenhouse horticulture, the application of green manures, stubbles and crop residues is generally limited. Some effective organic matter is added in the form of peat or compost in plant plugs, but soil amendments in the form of compost or manure are necessary to feed soil life and balance organic matter contents of the soil. The preferred type and amount of organic amendment depends on the specific soil characteristics.

About 3-4% organic matter will be decomposed annually in organic greenhouse soils in temperate regions. Decomposition rates will be higher on lighter, alkaline soils, and lower on heavier, acid soils. Decomposition rates will be much higher in a heated greenhouse or warmer climate than in a winter greenhouse or temperate region. In order to balance the decomposition of organic matter, fresh organic matter supply is necessary, through plant plugs, crop residues, compost or manure. The organic matter content that is desirable for a certain cropping system depends on soil type and climatic conditions. According to the European Soils Bureau Network[10], soils are at a risk of degradation below organic matter contents of 1.7%, as is commonly found in the majority of the Mediterranean countries. In temperate regions, organic matter contents of 3-5% are desirable in intensive greenhouse cultivation

Figure 1.7 *Greenhouses which are only heated in winter to keep them frost-free (left), have lower temperatures, and a slower organic matter break-down compared to year-round heated greenhouses (right).*

In order to reach a balanced organic matter level in soil, a specific amount of manure or compost is necessary. In greenhouses with temperate climate, an annual application of 31 tonnes manure or compost per hectare is sufficient to maintain organic matter levels of 2-3%, depending on soil type. Taking into account an additional 3 tonnes/ha of peat from plant plugs, soil organic matter contents of 4-6% may be possible. Higher levels of compost use (in the range of 100-200 tonnes/ha/yr) have increased average organic matter contents in Dutch greenhouses to >8%, but have unwanted by-effects, like nutrient losses, high EC levels, and plagues of wood louses and millipedes[14].

1.3.2 Storage, transport and transformation of nutrients

In organic greenhouse systems, composts are important sources of plant nutrients. Crop demands can be very high depending on the intensity of the cultivation system. Tomato yields of >40 kg/m^2 are common in year-round organic greenhouse cultivation in The Netherlands, and crop demands easily surpass 800 kg N/ha/yr[15]. A large part of this nitrogen demand is delivered by mineralization of soil organic matter, which has been built up by regular application of compost. The nutrient contents of input materials for compost are very variable, as are the nutrient concentrations in the finished product. Woody materials generally contain far less nutrients than lignin-poor materials. Animal manures are mostly rich in P and N, while grass or vegetable residues are rich in N and K. Consequently, the nutrient contents in different composts can differ by a factor of 3 to 4 (see Table 1.1). This implies that it is crucial to analyze the nutrient content of a specific compost, in order to be able to calculate the nutrient balance, and not to use average values taken from the literature. Another important point to consider is the availability of the different nutrients for the plant. The composting process itself does not dramatically influence the nutrient composition of the material, except for N. When the composting process is inappropriately managed, an important quantity of the mineralized N can be lost. Depending on compost maturity, only 0 to 10% of the N is available in the first year.

Table 1.1

Variability in chemical characteristics of composts in Switzerland (median values,with minimum and maximum values in parentheses). All feedstocks are source-separated[16]

Chemical characteristic	Compost for agricultural use	Compost for horticultural use	Compost for greenhouse cultivation and gardening
DM	50.8 (28.2-73.4)	56.7 (40.8-71.1)	56.3 (32.2-64.5)
OM	47.7 (17.0-80.1)	38.1 (23.9-54.7)	30.6 (20.9-52.8)
salt content	862 (361-1580)	787 (173-2657)	660 (328-1539)
pH	8.2 (7.5-8.7)	8.1 (7.6-8.7)	7.9 (7.2-8.5)
N	16.6 (8.7-26.0)	14.6 (9.2-27.6)	15.1 (8.6-25.2)
P	3.0 (1.7-6.1)	3.0 (1.3-12.7)	3.3 (2.1-8.8)
K	12.0 (5.7-25.2)	11.6 (2.2-20.7)	10.7 (5.5-27.8)
Mg	4.8 (3.6-10.3)	6.5 (4.4-10.7)	6.5 (4.4-13.3)
Ca	53.1 (24.0-83.7)	64.0 (35.0-91.5)	44.5 (29.5-69.4)
Fe	8.8 (2.9-16.7)	10.1 (5.4-14.7)	12.0 (6.1-15.8)

DM (dry matter) is given in % of fresh material, OM (organic matter) in % of DM, macronutrients (N, P, K, Mg, Ca) in g/kg DM, micronutrients (Fe) in mg/kg DM, salt contents in mg KCl/100 g fresh manure, pH is determined in 1:2 water extract.

Compost is a valuable source of organic matter, but it also contains many nutrients for crop production, including micronutrients. Proper use of compost is essential from both a production and an environmental point of view. Application rates that are too low may lead to nutrient deficiencies and low yields. Rates that are too high may foster nitrate leaching and phosphorus runoff.

Compost is used for both short- and long-term nutrient supply. Long-term experiments in Germany have shown that with regular application of compost (6-10 tonnes/ha/yr), the availability of P and K is 30-50% and 40-55%, respectively. At the experimental station of the Federal Republic Baden-Württemberg, correlations were found between the rates of compost-applied P and K and the increase in soil available P and K. The amount of available nutrients increased by 1.0 mg P_2O_5/100g soil and 1.3 mg K_2O/100g soil for each 100 kg of nutrient applied[17]. The estimation of N availability is more complex.

Most of the N in compost is in the organic form, and essentially all of the N in mature compost is organic. Organic N is in simple forms (amino acids) available for plant uptake, but microorganisms mostly outcompete plant roots in the uptake of free amino acids, and decompose organic N to its inorganic forms[18, 19]. Only a small part of N in compost is in inorganic forms. NH_4^+ (ammonium) and NH_3 (ammonia) are present in young composts. The NH_4-N fraction is readily available for plant uptake. Other inorganic forms such as NO_3^- (nitrate) and NO_2 (nitrite) are present in more mature composts, but their quantities are usually low. After the application of compost, the organic matter undergoes microbial transformations that release plant-available N over time. Denitrification, volatilization and leaching can result in N losses from the soil that reduce the amount of N that can be used by crops.

1.3.3 Soil structure, aggregate stability, water storage and transport

Soil structure basically describes the arrangement of particles and pores in soils. Soil structure can be viewed on different scales, and within these scales, different sized soil biota play a role in the creation, stabilization or degradation of soil aggregates[20]. The application of compost can have important effects on several aspects of soil structure. The addition of organic matter to soils in the form of compost can enhance the aggregate stability and hydraulic conductivity of soils. Amendments of between 10 and 30 ton/ha of municipal waste compost significantly increased the amount of water-stable aggregates, and enhanced microbial respiration, macroporosity and hydraulic conductivity. Microporosity was not affected[21]. The addition of both carbon-rich (C/N 108) and carbon-poorer (C/N 19.7) organic amendments to soils improved aggregate stability and influenced bacterial and fungal populations in soil. More specific research revealed that macro-aggregate formation was positively influenced by fungal activity but was not significantly affected by residue quality or bacterial activity[22]. Other experiments confirmed that there was no formation of macro-aggregates in the absence of fungal activity[23]. Experiments using compartments with combinations of mycorrhizal hyphae and/or roots, showed that both mycorrhizal hyphae and roots contribute individually to aggregate stability, and that their effects are cumulative when acting together. The experiments also suggested (but did not prove) a possible relationship between microbial numbers and aggregate stability[24].

The single application of 10 ton/ha compost in orchards has been shown to alter the community structure of the microflora even after a three-year period. The most pronounced changes were seen in the fungal community structure, but the bacterial community structure was also significantly changed[25]. In this orchard, mycorrhizal fungi were specifically increased by application of compost. As mentioned in the above paragraph, fungi and specifically mycorrhizae play an important role in the stimulation of aggregate stability.

How strongly can the compost microflora affect the indigenous microflora of the soil? And how important is the compost microflora when applying compost to a sterilized (e.g. steamed) soil? To answer these questions, experiments have been designed in which combinations of sterilized and unsterilized soil and compost were used. The experiments used low and high amounts of grape compost: 0.5% and 5% (w/w), which is equivalent to the application of 12.5 and 125 ton/ha compost, respectively, in a 25 cm topsoil layer. In these experiments, it was seen that adding sterilized compost or non-sterilized compost to a non-sterilized soil gave only a weak difference between the treatments. However, adding non-sterilized compost or sterilized compost to a sterilized soil gave a much stronger difference between the treatments[26]. What changes occurred when soil was sterilized?

Sterilization of soil caused a significant decrease in carbon mineralization and respiration. It also induced strong modifications of the genetic structure of the microbial community. The experiments also examined the short-term and long-term (6 months) effects of compost application. Even a relatively low dose of compost (12.5 ton/ha) in non-sterilized soil produced a weak but significant change in the microbial population structure in the first period after application. After 6 months however, this effect had disappeared, and the soil looked the same as if no compost had been applied. However, with a high dose of compost (125 ton/ha), after 6 months, the microbial community structure of the soil was still different. When comparing these effects of compost application to sterilized soil, a different picture emerges. Weak effects on the community structure of the soil were replaced by strong effects. These effects remained strong six months after application instead of only playing a role in the initial period after application. The authors suggested that most compost-borne micro-organisms are adapted to the compost environment (including pH, temperature, organic matter quality and quantity), and cannot survive in or adapt to soil conditions: most compost-born microorganisms are outcompeted by soil-born micro-organisms[26]. Important lessons can be drawn from these experiments regarding the application of compost after soil disinfestation: compost quality can determine strongly the microbial community in the soil for at least the following 6 months, and care should be taken of the quality of the applied compost.

Figure 1.8 *Earthworms play an important role in the formation of soil structure. Left: earthworm digging into a sharp-blocky structured soil. Right: earthworm burrows filled with worm-casts.*

Earthworm populations play an important role in the formation of macropores (Figure 1.8). Deep-burrowing so-called anecic earthworm species make individual semi-permanent, mainly vertical burrows, while endogeic earthworm species produce extensive networks which are more horizontally orientated. Water infiltration might be enhanced 10-fold or more, when a large earthworm population is present[20]. Epigeic species, like *Lumbricus rubellus*, are surface-dwelling, and survive mainly on raw humus. They contribute most to the formation of macropores in the top 10 cm of the topsoil, but in a soil without a litter layer, they can create burrows to at least 21 cm depth. Different endogeic species behave differently with regard to continuity of burrows in topsoil and subsoil, and with regard to the openness of the burrows to the soil surface. It has been suggested that ideal earthworm populations should consist of both deep-burrowing and topsoil-working species[27]. Urban compost amendments have been shown to increase natural populations of endogeic species up to 12-fold in clay loam, compared to plots receiving mineral fertilizer[28].

1.4 Visual soil assessment

Many soil types are used for horticultural production. Each type of soil has its own characteristics, strengths and weaknesses. Knowing the particularities of a farmer’s own soil is the first step in developing a sound soil management practice. The characteristics of the soil cannot only be judged by a chemical and/or biological soil analysis. A visual soil assessment in the field gives important information that is not revealed by laboratory analysis. Soil pits and spade analyses can both be helpful in visual soil assessments.

In the soil pit, the vertical profile of the soil can be examined. The uppermost layer of topsoil is the area in which the plants root, and also the space where most chemical and biological activity occurs. The upper layer will often be darker in colour (but not always), as it contains most of the soil organic matter. Below the topsoil are one or more, lighter coloured soil layers. Although biologically less active, these layers are still important for plant growth, and roots may find water and nutrients in these deeper layers, while preventing nutrient leaching from the subsoil. In a soil pit, you may also observe layers that are obstructions to plant growth, either caused by human influence (plough pans) or by natural soil development (movement of clay, calcium, iron or humus into hard or smeary layers, that obstruct root growth). Soil structure, texture, rooting intensity, degree of aeration, and the presence and activity of soil organisms can be observed directly in the field, and give important information on soil management options.

The uppermost layers of soil can also be examined by a simple 'spade' analysis, which is less labour intensive than a profile pit (Figure 1.9). Depending on the variability in the field, a spade test can be carried out in more places: headlands or gateways for example, can have different problems than the rest of the field. (Box 1.1).

Box 1.1 Spade analysis procedure

Remove with a spade an undisturbed spit of soil from the upper 30 cm layer:

- Choose an appropriate site in the field; during the growing season, you may choose a site close to the crop, in order to better examine root growth;
- Dig a small - 30 cm deep - pit into the soil;
- Loosen an undisturbed spit of approximately 10 cm thick at all sides by pushing the spade carefully in the soil at three sides;
- when pushing the spade in the third side, support the spit of soil while you remove it carefully from the pit, keeping it on the spade, and gently lay it on the ground.

Visual spade assessment:

- Examine if there are different soil layers visible;
- Examine the soil structural elements, by carefully breaking the clods apart. A knife or pocket lens may be helpful;
- Determine the volume of different structural elements within the soil layers;
- Determine the abundance and health of roots in the different layers. Notice abnormal growth (sudden change of direction, damaged or deteriorated roots, deformations caused by pathogens, root colour);
- Repeat the procedure for the 30-60 cm deep soil layer.

From a deeper soil pit, the following observations can be made:

- The distribution of different structural elements in the soil at different depths: angular blocky, sub-angular, granular or crumbly;
- The depth and number of roots: are they well-branched and numerous, or is rooting restricted, by restricted branching, or by growing sideways;
- The health of roots: colour (outside and inside), strength of the outer root layers, irregularities or deformations that indicate the presence of root pathogens, presence of nitrogen-fixing nodules (legumes);
- The presence of compact layers: plough pans, but also areas of clay, iron, calcium or organic matter accumulation;
- The activity of organisms in the soil: earthworm burrows and casts; the presence and abundance of earthworms and potworms (*Enchytraeidae*), springtails (*Collembola*), predatory mites, centipedes, millipedes and wood louses;
- The presence of crop residues and decaying roots in the soil layers;
- The presence of seashells or pieces of chalk;
- Degree of aeration and odour;
- The colour of the soil: layers and mottling (the presence of spots of a particular colour). Mottling may indicate that the soil is subject to waterlogging.

Figure 1.9 *A simple spade analysis can provide a quick scan of the soil situation in the field. Left: support the spit of soil while removing it from the pit, so that it remains intact. The aim is to examine an undisturbed layer of soil: the layer at the front, which is not touched by the spade. Right: From the spade different observations can be made, like rooting intensity, continuity or discontinuity of soil layers, distribution of organic matter and presence of earthworms or angular structures in the deeper soil layers.*

From the soil assessment in the field, the next step is to develop a soil management plan, including not only the type and amount of soil amendments, but also the frequency and depth of tillage, the use of crop rotation, rootstocks and water management. It may not be easy to determine which kind of manure or compost is most adequate in a certain situation, but based on the soil type and crop needs, some indications can be given. Both the development stage of the soil and the natural mineralization potential of the soil are important factors determining the choice of organic amendment. In a fast mineralizing, young calcareous soil, fast decomposing manure will provide even more nutrients to the plant, but will not support the long-term organic matter balance of the soil. Stable, composted manure or carbon-rich plant-based compost will in this case be more appropriate. However, when amendments with very high C/N ratios are applied, the risk of N immobilization may be increased, even in fast mineralizing, young soils. On the other hand, when growing crops on slowly mineralizing, weathered and acid soils, a fresh manure or relatively young compost will be better able to activate soil life, and add to both bacterial and earthworm activity[13]. By observing carefully the year-to-year development of the soil, the effect of management practices on the specific soil type can be gradually learned and better adapted to the needs of both the soil type and cropping system.

1.5 References

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