Compost effects on soil properties and plant growth

A thesis submitted to the University of Adelaide in fulfilment of the requirements for the degree of Doctor of Philosophy

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Dedicated to my father, Duong Ba Dong and my mother Nguyen Thi Kim Sanh

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Statements of Authorship

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ABSTRACT

Compost production is considered an economic and environmentally friendly means to reduce the waste going into landfill. Compost application can improve soil quality and productivity as well as sustainability of agricultural production by replenishing soil organic matter and supplying nutrients. Organic matter is a vital component of a healthy soil as it plays an important role in soil physical, chemical and biological fertility. In this project, four experiments were conducted to assess the effect of compost mulch on soil properties and plant growth and nutrient uptake as influenced by compost composition and particle size, soil type and time after application.

The first experiment was carried out using four composts from various feedstocks applied as mulch to a sandy loam. Their effect on soil properties, plant growth and nutrient uptake was assessed after 2, 4, 6, 9, 13 and 18 months. The composts were C1 and C2 (from organic fraction of municipal solid waste); C3 (from manure); C4 (from straw and manure). A soil without compost amendment was used as control. At each sampling date, the soil was sampled after removing the compost mulch and the remaining soil was planted with wheat; plant growth and nutrient uptake were determined after 4 weeks. The coarse-textured compost (C2) had the least effect on nutrient availability and plant growth despite moderate concentrations of available N and P in the compost. However, its total N and P concentrations were low which, together with the coarse texture resulted in low mobilisation rates. The other three composts increased soil aggregate stability and water holding capacity although there was no measurable increase in soil organic C, suggesting that the improved soil structure was due to microbial activity (bacterial slimes, fungal hyphae). These three composts also increased soil N and

P availability, plant growth and nutrient uptake with N and P availability increasing over time whereas plant growth was maximal after 4 months. The increased soil nutrient availability was due to two mechanisms: either release of P and N already present in available form in the composts or mobilisation of the nutrients during the experiment which varied with compost type.

Despite the fact that the beneficial effects of compost on soil properties are generally well-known, there are few systematic studies comparing the effects of composts on soils of different texture. The second experiment was conducted to assess the effects of two types of composts derived from different feedstocks: C1 (from garden waste) and C2 (from agricultural residues and manures) applied as mulch on three soils with different clay content (46%, 22% and 13%, hereafter referred to as S46, S22 and S13) on soil properties as well as on plant growth and nutrient uptake. Wheat plants were grown for 35 days and to grain filling (70 days). The soil was sampled after removal of the mulch layer. The composts reduced the soil pH by 0.3-0.7 units and slightly increased total organic C compared to unamended soil. Soil respiration was highest in S13, and at grain filling it was greater in soil amended with C2 than that amended with C1 and the non-amended soil. The addition of compost significantly increased soil cation exchange capacity (CEC) in S22 and S46, but not in S13 which had the lowest CEC among the soils. C2 increased the available P concentration and macro-aggregate stability in all soils compared to C1 and the unamended soil. Compost addition increased available N in S46 and S22 compared to the unamended soil with a stronger effect by C1. Both composts increased wheat growth and shoot P concentrations with the effect of C2 being greater than that of C1. Generally, the effect of soil type was greater than that of compost type. It is concluded that the effect of composts on soil properties and plant growth is strongly affected by soil properties.

There are few studies in which the effect of several composts applied as on soil properties and plant growth has been studied under controlled conditions. To address this knowledge gap, a third experiment was carried out with six types of composts applied as mulch on two soils (13% and 46% clay, referred to as S13 and S46). Wheat was grown and harvested at 42 days and at 77 days (grain filling). Composts differed in total and available N and P and particle size with C1, C3, C4 and C5 being fine-textured, whereas C2 and C6 were coarse-textured. Compost addition increased soil TOC and EC, but had no effect on pH. In all treatments, cumulative soil respiration was higher in S13 than in S46 and was increased by compost addition with the greatest increase with C2 and C6. Compared to the unamended soil, most composts (except C2) increased macroaggregate stability. Compost mulches significantly increased available P and N in both soils, except for C2. Compost mulches increased available N concentrations up to 6-fold in both soils with the strongest increase by C5. Most composts also increased wheat growth and shoot P and N concentrations, except C2 which decreased shoot N and P concentrations compared to the unamended soil. Most composts (except C2) increased mycorrhizal colonization by up to 50% compared to the unamended soil. It can be concluded that fine-textured compost mulches generally had a greater effect on soil properties and plant growth than coarse-textured composts. In this experiment, a given compost had similar effects in both soil types.

In most studies to date, compost effects on soils have been studied in the bulk soil without considering the distance from the compost. This distance could be important because the effects are likely to be greater in the immediate vicinity compared to further away. Thus by taking a bulk soil measurement, one may underestimate the effect in immediate vicinity of the compost whereas the effect in greater distance is overestimated. A fourth experiment was carried out to assess the effect of compost on soil properties in their immediate vicinity. This experiment was also used to assess the changes in nutrient concentrations withing the composts. Three composts from different feedstocks: C1 (from animal manures) and C2 and C3 (from the organic fraction and municipal solid waste) were applied as a layer which was separated from the soil by a mesh. Microcosms without compost served as controls. Microbial and chemical properties of the soil were determined at 0-5 and 5-10 mm distance from the mesh after 30 and 63 days. During the 63 day incubation, the total C, N and P and available N concentrations in the composts decreased whereas the available P concentration increased. The composts induced higher microbial biomass and activity, total organic C and available N and P concentrations up to 10 mm into the surrounding soil with greater effects after 30 than after 63 days. The nutrient concentrations were generally greater in soil adjacent to the two finer-textured composts with the higher nutrient concentration (C1 and C3) than in the coarser-textured compost (C2) which had lower nutrient concentrations. The 0-5 and 5-10 mm layers did not differ in most of the measured properties except for greater soil respiration and N and P availability in the 0-5 mm layer. It can be concluded that composts affect soil properties up to 10 mm distance but that the greatest effect on microbial activity is limited to the first 5 mm.

The experiments showed that compost properties, particularly particle size and nutrient concentration determine the effect of compost on soils. Finer composts have greater effects than coarse-textured composts. Nutrients released from composts may derive from the nutrients already available in the composts or may become mobilised after compost application. Compost effects were modulated by soil type and changed over time.

DECLARATION

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Chapter 1

Introduction and Review of Literature

1 Introduction

In many countries, a large proportion of municipal waste is not disposed properly posing a potential environmental threat due to the presence of pathogens and toxic pollutants (Darby et al., 2006; De Araújo et al., 2009). Landfill is problematic as it leads to pollution problems such as leachate and landfill gases, especially when disposing municipal solid waste with high moisture and organic content (CIWMB, 2004). Organic municipal waste and other organic material such as manure can be composted. Composting is an aerobic process during which the organic matter is decomposed to humus-like substances. The volume of the material decreases during composting and the resulting compost is nutrient rich and more stable than the original material (feedstock) and can improve soil quality and productivity as well as sustainability of agricultural production (Barral et al., 2009; Farrell and Jones, 2009). The cost of chemical fertilizers and the potential environmental risk posed by overuse have renewed the interest in using soil organic matter amendments such as plant residues, manures and composts.

However, compost properties vary widely depending on feedstocks and composting procedure (Bernal et al., 2009; Bertoldia et al., 1983). Efficient and optimal use of composts relies on a better understanding of the relationship between compost properties and their effect on soils, how this changes over time and it is modulated by soil type. This review covers compost production, compost properties and compost effects on soils and plants.

2 Composting

In Australia (excluding ACT and Victoria for which no data is available), 3765,000 t of compost were produced in 2006 and 4573,000 t in 2007 (21% increase) (W.M.A.A., 2007). Demand increases as land owners become more aware of the poor state of their soils, because under long-term cultivation, soil organic matter may be depleted.

Compost is defined as stable aerobically decomposed organic matter which is the result of a managed decomposition process. During this process, a succession of aerobic micro-organisms break down and transform organic material into a range of increasingly complex organic substances (Bastida et al., 2010; CIWMB, 2004; Epstein, 1997; Paulin and O'Malley, 2008). According to Wiley et al. (1955) and Epstein (1997), microorganisms use organic matter (feedstocks) as a food source and then produce heat, carbon dioxide, water vapour and a range of organic compounds (Fig. 2.1). Mature composts are stable and have pleasant smell, but if the composting process is ended prematurely, the resulting immature compost may have negative effects on soils and plants and have a bad odor (Epstein, 1997; Farrell and Jones, 2009). Vermicomposts are a special class of composts where earthworms are introduced when the compost has cooled; the final compost contains a large proportion of earthworm casts.

The composting process is affected by starting materials (feedstocks), decomposing organisms and environmental factors (Annabi et al., 2007; Farrell and Jones, 2009).

Figure 2 The composting process

(Epstein, 1997)

Compost can be derived from a number of feedstock materials including woody (trees, shrubs) and herbaceous (turfgrass and small flowering plants) green waste, crop residues, biosolids (sewage sludge), wood by-products, animal manures, biodegradable packaging and building materials and food scraps. These feedstocks differ substantially in chemical composition, particle size and thus decomposition rates (Cayuela et al., 2009; De Araújo et al., 2009).

2.1 Changes in chemical properties during the composting process

In general, compost pH changes over time as a result of formation and break-down of organic acids released from the decaying starting materials as well as ammonification and nitrification. The pH usually approaches neutrality (pH 7) during the maturation phase but also depends on the starting materials.

Depending on the starting material, compost electrical conductivity (EC) as a measure of the soluble salt content may be quite high. Repeated addition of high salt compost may result in increases in soil salinity to levels that are toxic to salt-sensitive plants; therefore the EC of mature compost should only range from 1 to 3 dS m^{-1} (Tognetti et al., 2007).

During composting, organic compounds are transformed into more stable and complex organic matter via humification (Epstein, 1997; Hernandez et al., 2006; Lee et al., 2009). The rate and extent of these transformations will depend on the nature of the starting materials and composting conditions. During composting, the organic matter initially undergoes a rapid decomposition but later, during humification the decomposition rate are low as substrate availability is low and more complex and recalcitrant organic compounds predominate (Ciavatta et al., 1993; Kawasaki et al., 2008).

Compost C is quite resistant to further decomposition; thus compost may be useful to increase C sequestration in soils (Whalen et al., 2008). Indeed, two years after the last application, 37-67% of applied C was still retained in the soil, with 19-34% of soil C derived from compost (Lynch et al., 2006).

According to Whalen et al. (2008) and Ge et al. *(*2010*)*, an initial C/N ratio of the composting material in the range of 25 to 30:1 is ideal for the activity of compost microbes and this balance can be achieved by mixing starting materials with different C/N ratios.

The ratio of NH_4^+/NO_3^- is a critical measure to monitor the process of composting. Until the end of the thermophilic phase, ammonification dominates whereas nitrification increases after the thermophilic stage (Eklind and Kirchmann, 2000; Mahimairaja et al., 1994). Loss of N in during composting may be by volatilization of ammonia (NH_3), leaching and denitrification which accounted for 12 and 28% of the initial N. Denitrification is an anaerobic process which can be minimized by ensuring that the compost remains well aerated (Mahimairaja et al., 1995; Tiquia and Tam, 2000).

The concentrations of P and K increase substantially during composting (Eneji et al., 2001; Sharpley and Moyer, 2000), but the mechanisms behind those increases are unclear. Eneji et al. (2001) found that, after the composting process was completed, the concentrations of P increased by 31%, of K by 12%. The proportion of various P forms in compost is influenced by feedstock and composting methods (Tambone et al., 2007). In final compost products, compost P is about 45 to 90% in inorganic and the rest is organic form (Epstein, 1997). K remains mostly in water-soluble form over the entire composting process and can be lost via leaching (Eneji et al., 2001).

2.2 Changes in physical properties during the composting process

Moisture is an important environmental factors affecting microbial activity and therefore temperature and composting rate.

According to Zameer et al. (2010) and Tiquia et al. (1998), a moisture content of 50-65% is generally considered optimal for composting. Too little moisture (<30%) inhibits bacterial activity whereas high moisture content (>65%) results in a slow decomposition, anaerobic conditions, bad odour and nutrient leaching.

Temperature is also one of the key factors affecting the composting process. Compost heat is produced as a by-product of microbial breakdown of organic matter (Nakasaki et al., 1985; Venglovsky et al., 2005). The heat production depends on the size of the pile, its moisture content, aeration, and the C/N ratio of staring materials. According to Epstein (1997), temperature changes during composting is mainly divided into two distinct phases of, namely mesophilic phase (<45°C) and thermophilic phase (>45°C). A rise of temperature during thermophilic stage leads to pasteurization of pathogenic microorganisms in the materials, promotion of water evaporation from the composting solid materials, and acceleration of the rate of decomposition of organic matter in the composting materials (Margesin et al., 2006; Nakasaki et al., 1985). However, if the temperature during the thermophilic phase is higher than 70°C, microbial activity will be inhibited which can negatively influence compost quality or maturity (Lynch et al., 2005; Margesin et al., 2006). The temperature decreases to ambient when the compost is mature.

2.3 Changes in biological properties during the composting process

The activity of a number of enzymes such as dehydrogenase, urease, beta-glucosidase, phosphatase and arylsulphatase is high in the initial phase of composting and decreases over time (Castaldi et al., 2008; Tejada et al., 2009a). Changes in substrate composition will lead to shifts of microbial populations which are responsible for producing specific enzymes breaking down different substances at different composting stages (Albrecht et al., 2010; Jarvis et al., 2009; Liew et al., 2009).

During the composting process, respiration rates are initially high, but decrease with composting time as dissolved organic C (DOC) concentrations decrease (Abid et al., 2007; Gattinger et al., 2004; Said-Pullicino and Gigliotti, 2007). Compost is considered mature and stable when the respiration rate is less than 5 mg CO_2-C g compost^{-1} day^{-1} (Epstein, 1997; Said-Pullicino and Gigliotti, 2007).

Changes in chemical and physical properties of the compost result in shifts in the activity and composition of microorganisms in the compost (Epstein, 1997), with mesophilic microorganisms (mesophiles) dominating in the initial and final phases, whereas thermophilic microorganisms (thermophiles) dominate in the middle phase when the temperature is high (Amir et al., 2008; Paul and Clark, 1996). Bacteria dominate in the early stages of composting because they are generally more competitive than fungi and actinomycetes in the presence of easily degradable compounds (Ryckeboer et al., 2003). As the relative concentration of aromatic and recalcitrant compounds in the remaining material increases, fungi and actinomycetes become dominant because many bacteria lack the specialized enzymes required to break down and utilise aromatic compounds (Amir et al., 2008; Paul and Clark, 1996). Actinomycetes is only present during stabilisation and curing phases and together with fungi are able to degrade resistant polymers (Bernal et al., 2009).

3. Effects of compost on soil

According to De Bertoldi et al. (1983) and Bernal et al. (2009), composts have several advantages compared to plant residues when applied to soils, such as reduced volume, slower mineralization rates and recycling of municipal biosolid wastes. Compost has two main effects on soils, particularly nutrient-poor soils: replenish soil organic matter and supply plant nutrients (Sanchez-Mondero et al., 2004; Tejada et al., 2009b). Organic matter plays a crucial role in improving physical, chemical and biological properties of soils. Soil structure can be improved by the binding between soil organic matter and clay particles via cation bridges and through stimulation of microbial activity and root growth (Farrell and

Jones, 2009; Gao et al., 2010). According to Tisdall and Oades (1982), organic matter can indirectly improve soil structure by increasing microbial activity and thus production of microbial slimes, fungal hyphae and/or roots bind aggregates together. Organic matter is a significant reservoir of nutrients and can retain nutrients in a plant-available form (Baldock, 2007).

Other beneficial effects of composts include increasing water holding capacity and plant water availability (CIWMB, 2004; Curtis and Claassen, 2005; Farrell and Jones, 2009), decreasing leaching of nutrients (Gale et al., 2006; Hepperly et al., 2009), reducing erosion and evaporation and prevention of plant diseases (Arthur et al., 2010; Gershuny, 1994). Further, compost can act as a long-term slow release fertiliser. However, the application of immature compost can have negative effects on plant growth due to its unpleasant or nuisance odour production, potential to inhibit plant growth and reduce N availability in the soil. The beneficial effects of compost are only achieved when mature compost is added to soil.

3.1 Application methods of composts (incorporation and mulching)

In agriculture, there are two common methods for applying composts to soil: incorporation and mulching (Bastida et al., 2010; Cogger et al., 2008). Compost incorporation into the top few centimetres increases accessibility for soil microbes and also contact with the plant roots, and thus have a greater effect on soil C, N, and bulk density than surface application (mulching)(Cogger et al., 2008). Mulching is a common in horticulture and agriculture in dry climates because it minimizes water loss by evaporation (Agassi et al., 1998; Agassi et al., 2004; Gonzalez and Cooperband, 2002; Tu et al., 2006). Compared to incorporation, the effect of mulching on the underlying soil can be expected to be smaller as it is limited to soluble compounds leaching from the mulch layer into the soil and due to the lower accessibility to soil organisms (Gonzalez and Cooperband, 2002). Compost with a coarse texture is considered the best for mulching because it allows water and air to move through to the soil underneath. It also decomposes slowly and is therefore long-lasting. Fine textured material can also be used as mulch but if applied too thickly it can trap water and prevent it from reaching the soil; this only generally occurs if the compost is applied in a layer of more than 5 cm thickness (Agassi et al., 1998; Paulin and O'Malley, 2008).

3.2 Effects on soil chemical properties

- pH

The effect of compost addition on soil pH is not well understood. Mature composts should have neutral or slightly alkaline pH. Addition of compost from manure has been reported to both increase and decrease soil pH and have the ability to buffer soil pH (Butler et al., 2008; Johnson et al., 2006), depending on compost as well as soil pH. Soil pH is one of the most decisive factors affecting metal solubility, plant nutrient uptake and movement; plant growth, microbial activity and many other attributes and reactions (Epstein, 1997; Garcia-Gil et al., 2004). An increase of soil pH following addition of compost from broiler litter is mainly due to addition of basic cations, ammonification and production of NH_3 during decomposition of the added compost (Hubbard et al., 2008). Additionally, adsorption of H^+ ions, development of reducing conditions due to increased microbial activity and displacement of hydroxyls from sesquioxide surfaces by organic anions can lead to pH increase in soils amended with compost (Pocknee and Sumner, 1997). On the other hand, soil pH can also decrease after application of compost from rice straw mixed with agro-industrial wastes due to the release of H^+ via nitrification and/or the production of organic acids during decomposition (Bolan and Hedley, 2003; Rashad et al., 2011).

- Cation exchange capacity

Composts have a high cation exchange capacity and can therefore increase soil CEC when incorporated. Humic acids, major components of compost can bind cations because they contain carboxylic acid groups, which can bind positively charged multivalent ions (Mg^{2+}, Ca^{2+}, Fe^{2+}, Fe^{3+}, trace elements, but also Cd^{2+} and Pb^{2+}) (Pedra et al., 2008).

- Soil organic matter

Most essential nutrients in compost are in organic forms which are released slowly and are less subject to leaching compared to inorganic fertilisers (Larney et al., 2008). The incorporation of compost derived from biogenic household and garden waste to soils increases soil carbon and total N concentrations (Leifeld et al., 2002; Mylavarapu and Zinati, 2009). Whalen et al. (2008) reported that, after 5 years of annual additions of compost derived from cattle manure, organic C and total N concentrations were increased by up to 2.02 t C ha^{-1} yr^{-1} and 0.24 t N ha^{-1} yr^{-1}; respectively. Compared to manures or fresh plant residues, compost C is poorly decomposable; thus compost may be useful to increase C sequestration in soils. Lynch (2006) showed that two years after the last application of compost from dairy manure and sewage sludge, 37-67 % of applied C was still retained in the soil, with 19-34% of soil C derived from compost. Compost C is mainly stored in macro-aggregates (Lee et al., 2009).

- Nutrient concentration

The application of compost from municipal solid waste (MSW) and dairy manure to soils can result in a significant increase in concentrations of N, P and other nutrients in soil, even several years after compost application (Butler et al., 2008; Soumare et al., 2003). However, increased microbial activity can also increase N mineralization and potential denitrification (Dambreville et al., 2006) and may therefore increase N loss via leaching and volatilization (Hadas et al., 2004; Odlare and Pell, 2009).

3.3 Effects on soil physical properties

- Water availability and retention

Application of compost from MSWs to soils has been shown to limit water loss via evaporation, increase soil organic matter and thus water retention and availability (Or and Wraith, 2000; Weber et al., 2002). In a 5 y field experiment with compost from cattle manure, Celik et al. (2004) reported that the available water content of soils increased by 58–86% in the compost-amended soil as a result of increase in micro- and macro-porosity. By increasing the water retention of soils, more water can be conserved over the growing season in arid or semiarid regions and in some cases, increase yields of perennial crops (Chantigny et al., 2002; Fageria, 2002; Moran and Schupp, 2003).

- Soil structure

Good soil structure favours gas and water transfer in soils, seed germination, and root growth as well as reduce susceptibility to erosion. The gummy, spongy texture of the humus-like substances in the compost facilitates formation of aggregates (Mylavarapu and Zinati, 2009; Sodhi et al., 2009; Tejada et al., 2009b). As a result of increasing microbial activity, soil aggregation can also be improved by bacterial slimes and fungal hyphae (Tisdall and Oades, 1982). In clay soils, addition of compost from MSWs can improve drainage and aeration (Avnimelech et al., 1990) and these benefits may occur within one year after composted cattle manure application (Whalen et al., 2003). However, the effect of compost from MSWs on aggregate stability may be soil type-dependent as Yuksek et al. (2009) and Duong et al. (2011) found that compost increased aggregate stability in lighter or medium textured soils but not in sandy or heavy-textured soils.

3.4 Effects on biological properties

The addition of compost to soils affects soil microorganisms directly by providing a source of nutrients and indirectly by changing chemical and physical soil properties. Compost stimulates microbial growth and activity, but not to the extent as fresh plant residues because it is already decomposed. Compost generally increases the abundance of soil organisms (including earthworms) (Cheng and Grewal, 2009; Paulin and O'Malley, 2008; Sutton-Grier et al., 2010).

Addition of compost from various feestocks has been shown to increase the abundance of Gram-positive bacteria (Islam et al., 2009), the density of ammonia oxidisers and denitrifiers in soil (Bastida et al., 2008), as well as soil respiration (Iovieno et al., 2009), the activity of various enzymes (Antonious, 2009; Bastida et al., 2008; Crecchio et al., 2001) and potential nitrification and denitrification (Bastida et al., 2008; Sutton-Grier et al., 2010). These changes will affect nutrient availability to plants and nutrient movement in soils.

Changes in microbial activity and community structure after compost application can lead to increased suppression of soil-borne plant pathogens such as *Fusarium oxysporum f.sp. lini, Phytophthora cinnamomi* and *Meloidogyne hapla* (Lozano et al., 2009) and enhance degradation of organic pollutants such as polycyclic aromatic hydrocarbons (PAHs) (Yuan et al., 2009), and fuel oil (Jorgensen et al., 2000). However, the effects of compost application on soil microbes may be transient. Crecchio (2001) reported that two years after addition of compost from MSWs the bacterial community composition was similar to that in the unamended control due to the depletion of substrate added with the compost.

4 Effects of compost on plant growth and nutrient uptake

Applying compost to soils can increase plant nutrient availability (Epstein, 1997; Heymann et al., 2005; Kawasaki et al., 2008; Poll et al., 2008). Compared to the same amount of N and P added, plant N and P uptake from compost may be lower than that from inorganic N fertiliser, because the organic N in the compost has to be mineralised before it can be taken up by plants or because of microbial immobilisation of N (Ebid, 2008; Odlare and Pell, 2009; Vance et al., 1987). However, initial slow mineralisation can sustain the release of N for the following seasons; over a 2 year period, 36-44% of compost N was mineralised (Passoni and Bonn, 2009). Compost from fruit residues, manure, and kitchen waste can also increase the retention of applied fertilizer N in the soil-plant system by stimulation of plant N uptake and microbial immobilisation and reduced N leaching and gaseous losses (Steiner et al., 2008; Vance et al., 1987). The effects of compost on soil properties and plant growth and how they are modulated by soil and compost properties are summarized in Fig. 4.

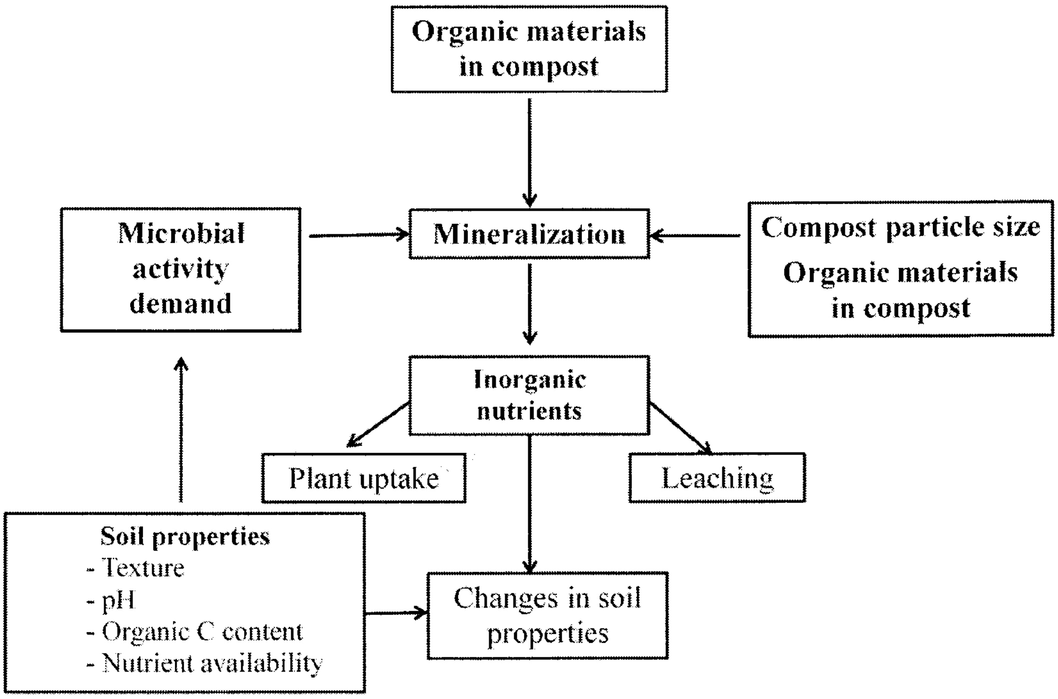

Fig. 4 Schematic diagram of mineralization of compost after application to soil and the factors influencing mineralization and the effect of compost on plants and soils

A study of Curtis and Claassen (2005) showed that incorporation of compost (24% v/v) from yard waste resulted in greater than a 2-fold increase in plant-water availability and increased the ability of the plants to access this water resource through greater root proliferation.

Compost can stimulate plant growth, root development and thus nutrient uptake (Lopez-Bucio et al., 2003; Oworu et al., 2010; Soumare et al., 2003; Walker and Bernal, 2008). Humic substances, the major component of soil organic matter in composts, can increase shoot biomass via hormonal effects on root elongation and plant development (Atiyeh et al., 2002; Lazcano et al., 2009; Nardi et al., 2002; Zandonadi et al., 2007).

To summarize, compost addition can increase soil nutrient availability and thereby nutrient uptake by the plants. This effect can be direct or indirect. Direct effects are via nutrients added with the compost whereas indirect effects are via increased microbial activity, improved soil structure or nutrient and water retention. Microbial activity can increase nutrient mobilisation, but may also result in immobilisation of nutrients. The improved soil structure and water retention will promote root growth and thus the soil volume accessed by the plant.

5 Conclusions and research gaps

Fig. 5 summarized factors influencing compost properties and compost induced changes in soil properties and plant growth which can be modulated by application method, time since application and soil properties. Research gaps that will be addressed in this thesis are indicated by a question mark.

Composts have been shown to have many beneficial effects on soils and plants, however their effectiveness may be limited because of a lack of understanding of the link between compost properties and its effect on soil properties, plant growth and nutrient uptake in the short (days to 4 months after a single application) or medium term (months to years after a single application). In the diagram above, these research gaps to be addressed in this thesis are indicated by question marks. The research will allow a better understanding of the beneficial effects of compost on soil properties thereby contributing to more efficient use of this resource as well as to environmental and agricultural sustainability.

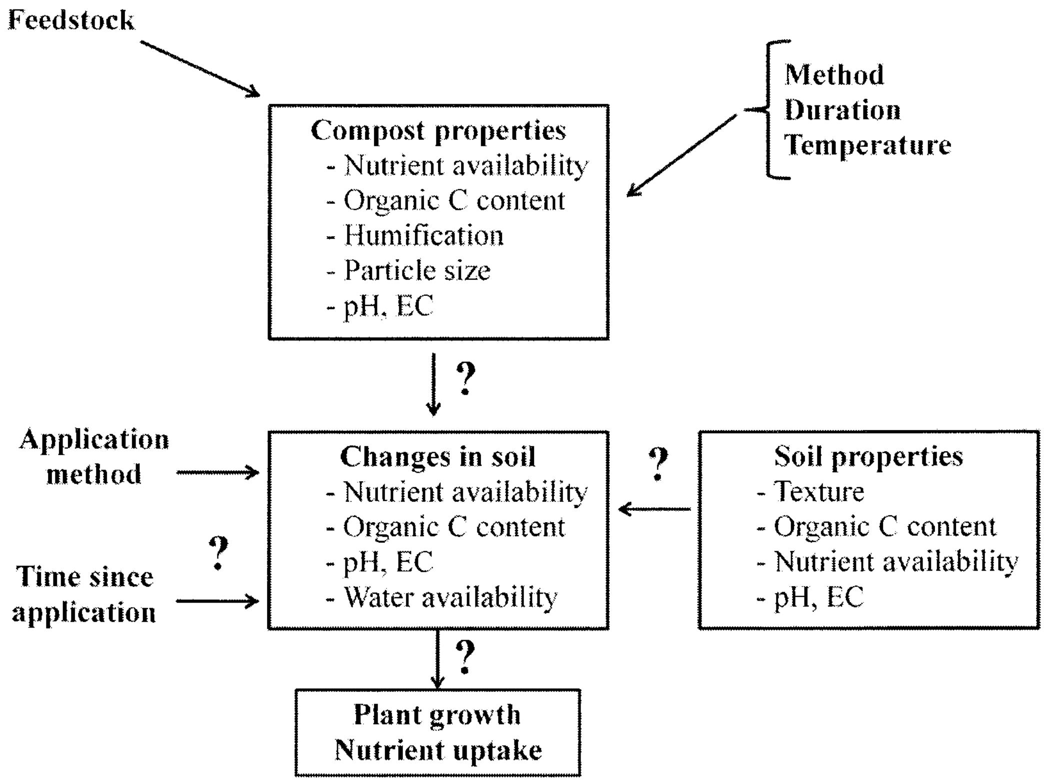

Fig. 5 The summary of the literature review

Thus, the present study has the following aims:

1) Determine how composts effects on soil properties and plant growth change over the first 18 months after application (Chapter 2)
2) Assess the effect of composts in soils of different texture on soil properties, plant growth and nutrient uptake (Chapter 3)
3) Investigate how composts with different properties affect soil properties, plant growth and nutrient uptake (Chapter 4)
4) Study the effect of composts on soil properties in their immediate vicinity (Chapter 5)

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Chapter 2

Time-dependent effects of different composts on soil properties, plant growth and nutrient uptake

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Time-dependent effects of different composts on soil properties, plant growth and nutrient uptake

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Abstract

Although the beneficial effects of composts on plant growth and soil properties have been studied extensively, there are few studies in which the effect of a single application of composts was studied at regular intervals over an 18-month period. Therefore it is not known if and how much the effect of composts changes over the first 1.5 years after application. Such information is required to determine the application frequency of composts to achieve maximum benefit. Four composts from various feedstocks were applied as 2.5-cm thick mulch layer to a sandy loam and their effect on soil properties, plant growth and nutrient uptake studied after 2, 4, 6, 9, 13 and 18 months during which the pots were kept outside exposed to natural rainfall and temperatures. The compost treatments were C1 and C2 (from organic fraction of municipal solid waste); C3 (from kitchen waste and animal manure); C4 (from straw and chicken manure). A soil without compost amendment was used as control. At each sampling date, the soil was sampled after removing the compost mulch and the remaining soil was planted with wheat; plant growth and nutrient uptake were determined after 4 weeks. The coarse-textured compost (C2) had the least effect on nutrient availability and plant growth despite moderate concentrations of available N and P in the compost. However, its total N and P concentrations were low which, together with the coarse texture resulted in low mobilisation rates. The other three composts increased aggregate stability and water holding capacity although there was no measurable increase in soil organic C, suggesting that the improved soil structure was due to microbial activity (bacterial slimes, fungal hyphae). These three composts also increased soil N and P availability, plant growth and nutrient uptake with N and P availability increasing over time whereas plant growth was maximal after 4 months. The increased soil nutrient availability was due to two mechanisms which varied with

compost type: either release of P and N already present in available form in the composts or mobilisation of the nutrients during the experiment. The mobilisation rate varied with compost type.

Keywords: Compost mulch; Municipal solid waste; Nutrient availability; Nutrient mobilisation; Single compost application.

Introduction

Intensive agriculture may result in soil organic matter loss which has negative implications for soil fertility and sustainability. There are various options to increase soil organic matter content, either by decreasing decomposition rate e.g. by reduced tillage, or by increasing organic matter input, e.g. by application of residue, manure or compost. Compost application has two main effects on soils, particularly nutrient-poor soils: addition of soil organic matter and supply plant nutrients (Sanchez-Monedero *et al.* 2004; Tejada *et al.* 2009). Organic matter plays a crucial role in improving physical, chemical and biological properties of soils. Soil structure is improved by the binding clay particles to soil organic matter via cation bridges and through stimulation of microbial activity and root growth (Farrell and Jones 2009; Gao *et al.* 2010). Compared to residue or manure application, composts contain highly degraded organic material (Mylavarapu and Zinati 2009; Zameer *et al.* 2010) and may therefore have longer-lasting effects than the more rapidly decomposing residues and manures.

In agriculture, compost can be used as a mulch or mixed with the top few centimetres of the soil to reduce erosion and evaporation and improve soil structure and aggregation (Arthur *et al.* 2010; Gershuny 1994). Compost mulching is wide-spread in viticulture and minimum tillage agriculture particularly in semi-arid regions where reducing water loss by evaporation is critical to ensure crop growth. Further, compost can also act as a long-term slow release fertiliser which increases nutrient availability. This aspect of composts will become increasingly important with inorganic fertiliser prices increasing because of high energy prices and limited reserves.

Compost properties are dependent on compost feedstocks, composting condition and duration. As a result, composts differ in physical and chemical properties and will thus differ in effects on soil properties (Eneji *et al.* 2001; Kawasaki *et al.* 2008).

Although the effect of compost application on various soil properties in the short- and long-term is well-documented, there have been very few studies evaluating the effects of compost at regular intervals in the first 1-2 years. In field trials, Bouzaiane *et al.* (2007) and Weber *et al.* (2003) sampled the soils annually over three years after a single application of compost as mulch. Wright *et al.* (2008) sampled every 3-5 months over 29 months after incorporation of compost. However, little is known about the effect of compost applied as mulch on nutrient availability over the first 18 months with sampling every 3 months. Further, none of the studies mentioned above investigated how the composts affected plant growth at the different sampling times. The aim of this study was to evaluate the effect of a single application of four different composts applied as mulch to a sandy loam soil on soil physical, chemical and biological properties as well as plant growth and nutrient uptake in a bioassay.

Materials and Methods

Experimental design

The soil used for the experiment was a Red Brown Earth soil of the Urrbrae series (Chittleborough and Oades 1979). The top 0-10 cm were collected, air-dried and sieved to <5 mm. It has the following properties: sandy loam, pH (1:5 water) 6.7, EC 0.08 dS m^{-1}, available P 34.7 mg kg^{-1}, total P 0.4 g kg^{-1}; total organic C 10.5 g kg^{-1}, dissolved organic C 1.4 mg kg^{-1}, available N 12.0 mg kg^{-1}; total N 1.5g kg^{-1}; and water-holding capacity (WHC) 250 g kg^{-1}.

The soil was wetted to 85% field capacity and the composts were applied as a 2.5 cm layer on the soil surface corresponding to 122, 100, 127 and 110 g moist compost for C1 to C4. Previous studies (Mat Hassan *et al.* 2011; Setia *et al.* 2011) had shown that soil respiration and plant growth were maximal at this water content in a soil of this texture. In this study, the following five treatments (with 4 replicates per sampling date) were set up with four types of composts applied as mulch, namely: C1 and C2 (from the organic fraction of municipal solid waste); C3 (from animal manure) and C4 (from straw and animal manure).

The 1-kg pots were kept outdoors on the Waite campus, The University of Adelaide, from July 2010 (winter) to November 2011 (spring). During this time, they received water only from the natural precipitation. Holes in the bottom of the pots allowed drainage and prevented water saturation. This location has a Mediterranean climate with a mean annual rainfall of 657 mm in 2010 and of 595 mm in 2011, most of which falls in the months of May to September (BoM 2012).

At the pots were destructively sampled at 2, 4, 6, 9, 13 and 18 months after compost application (corresponding to Sept. 2010, Nov. 2010, Apr. 2011, Jul 2011 and Dec 2011) for determination of the properties listed below. At each sampling date, the compost layer was removed, only the soil was analysed for the properties mentioned below. The soil remaining in the pots was used for a bioassay in which wheat (*Triticum aestivum* cv. Krichauff) was grown for 4 weeks to measure biomass and nutrient uptake.

Analyses

Soil and compost pH and electrical conductivity (EC) were measured in a 1:5 soil/water suspension (w/w) after 1 h end-over-end shaking at 25°C. The EC is a measure of the concentration of soluble salts in a solution with 1 dS m^{-1} being equivalent to 585 mg NaCl l^{-1}. Field capacity was measured using a pressure plate connected to a 100-cm water column ($\Psi m = -10$ kPa) (Klute 1986). Total N and P were determined as described below for the plant material. Inorganic N (NH_4^+-N and NO_3^--N) was extracted with 2M KCl at a 1:10 dry soil: solution ratio with 1h shaking (Keeney and Nelson 1982). Ammonium-N was measured by the nitroprusside/dichloro-S-triazine modification (Blakemore *et al.* 1987) of the Berthelot indophenol reaction at the wavelength of 650 nm. Nitrate-N was measured by the cadmium reduction method (Henriksen and Selmer-Olsen 1970). Available P was extracted from 2 g of freeze-dried soil with anion exchange resin membranes following Kouno *et al.* (1995); the P concentration was measured colorimetrically as described by Murphy and Riley (1962). Total organic C (TOC) was measured using wet digestion with sulphuric acid and an aqueous dichromate mixture; the digests were back-titrated for the residual potassium dichromate with ferrous sulphate (Walkley and Black 1934). Soil aggregate size distribution were measured using a modification of the wet-sieving method of Six *et al.* (1998) and Cambardella and Elliott (1994) in which 25 g of air dried soil was sieved to 5 mm and then wet-sieved for 3 minutes on an nest of four stacked sieves in the order 2000 µm, 1000 µm, 500 µm and 250 µm in RO water vertically at an amplitude of 3 cm at 25 cycles per minutes. The water-stable aggregates were then grouped into >1 and <1 mm size classes. For dissolved organic C (DOC), 5 g of freeze-dried soil were shaken with 25 mL distilled water (1:5 w/v soil: solution ratio) for 60 min at a speed of 200 rpm. The soil extracts were then centrifuged at 28,200×g for 10 min and the supernatant vacuum-filtered and stored at -20°C until analysis. The C concentrations in the extracts were measured by titrating 4 mL of extract against 33 mM ferrous ammonium sulphate hexahydrate after adding 1.0 mL 66.7 mM potassium dichromate and 3-4 drops o-phenanthroline monohydrate indicator solution (Anderson and Ingram 1993).

The method to determine the germination index (GI) was adapted from Zucconi et al. (1981) using *Triticum aestivum* L as test plant (three replicates). Ten grams of compost were shaken with 100 mL distilled water for 1 hour, centrifuged for 15 minutes at 10,600×g and the supernatants filtered. Ten wheat seeds were placed on filter paper in a Petri dish of 10 cm diameter and two mL of the extract was added. Two mL of reverse osmosis (RO) water were used for the control. After 48 hours, the root length of each wheat seedling was measured. If the seeds did not germinate, their root length was considered to be zero. The germination index is expressed as a percentage based on total length of roots on the compost test plates × 100 and divided by total length of roots on the control plates.

For plant analyses, at harvest, the shoots were cut at the soil surface, rinsed in RO water, oven-dried at 65°C for three days, and then ground. For determination of total P of soil and shoots, 100 mg of air-dried soil or 250 mg of dry plant material were digested by adding 7 mL of nitric and perchloric acid mixture (6:1). Total P was measured using the vanado-molybdate method (Hanson 1950; Kitson and Mellon 1944). Total N in shoots and soil was determined using the *yellow ammonium*-molybdate *method* in Bradstreet (1965) modified by Murphy and Riley (1962).

Statistical analysis

The data was statistically analysed by two-way analysis of variance (composts × sampling dates) (GenStat® for Windows 11.0, VSN Int. Ltd, UK, 2005). Tukey test and linear regression were used to determine significant differences and correlations of treatments in the measured parameters. Differences mentioned in the following refer to $P \leq 0.05$.

Results

Compost properties

The four composts differed in a range of properties (Table 1). Compost 1 was fine textured and had the highest concentration of total N and dissolved organic C. Compost 2 was coarse-textured and had the highest total organic C and water content, but the lowest pH. The EC was highest in C3 which was coarse-textured and had high concentrations of available N and total P. Compost 4 was medium-textured and had the highest concentration of available P and highest pH, but the lowest EC. Compost 4 had the highest germination index indicating that it was non-toxic whereas the germination indices of C1, C2 and C3 ranged from 61 to 80% indicating moderate phytotoxicity (Sanchez-Monedero *et al.* 2001; Zucconi *et al.* 1981).

Soil properties

From 9 months onwards, the field capacity in the soil amended with C1, C3 and C4 was significantly higher than in the soil amended with C2 and the unamended soil (increase by 10-30%) (data not shown).

Water-stable aggregates were determined only at the end of the experiment, 18 months after compost application (Fig. 1). The proportion of aggregates > 1 mm was greater in the soils amended with C1, C3 and C4 than in the soil amended with C2 and the unamended soil.

The soil pH did not change significantly over time and varied from 6.1 to 7.0. At the end of the experiment (18 months), the soil pH was higher in the soils amended with C1, C2 and C4 than in the unamended soil and the soil amended with C3, with greatest increase with C1 (7.4) (data not shown). The EC was increased by addition of C1, C3 and C4 compared to C2 and the unamended soil, and did not change over time, but it was below 0.25 dS m^{-1} in all treatments, indicating that the soils were not saline (data not shown).

The total organic C concentration was not affected by compost addition or compost type and did not change significantly over time, except in the soil amended with C2 after 18 months where the total organic C concentration was significantly lower (about 40%) than in the other treatments. The dissolved organic C concentration did not change significantly over time but was significantly higher than the unamended soil in the soil amended with C2 after 6 months and in the soil amended with C4 after 6, 9 and 13 months (Table 2).

The available P concentration significantly increased over time in the soils amended with C1, C3 and C4 but not in the unamended soil and the soil amended with C2 (Fig. 2a). Compared to the unamended soil, the available P concentration was always higher in the soils amended with C4 and C3 whereas from (6 months) onwards it was lower in the soil amended with C2 with differences becoming more evident over time. The available P in the soil concentration was positively correlated with the concentrations of available P and total P of the composts (r^2=0.71 and 0.51, $P<0.001$).

Compared to the unamended soil, application of C1 and C3 increased the concentration of available N 2-4 fold from 4 months onwards (Fig. 2b). Compost 4 did not affect available N concentration in the first 6 months but then increased it to concentrations similar to those of C1 and C3. Compost 2 had no effect on available N concentrations compared to the unamended soil. Soil available N was positively correlated with available and total N of the composts (r^2=0.86 and 0.53, P<0.001).

Shoot dry matter of wheat grown for 4 weeks in soil sampled at different times after the start of the experiment was highest in soil sampled after 4 months but then declined, being similar at the sampling after 9 months as after 2 months. But it increased again in soils sampled at 13 and 18 months amended with C1, C3 and C4 (Fig. 3). Compared to the unamended soil, shoot dry weight was always higher in soil amended with C4 and at most sampling times in soil amended with C1 and C3. Addition of C2 decreased shoot biomass compared to the unamended soil in soil sampled after 4 and 6 months, but had no effect later.

Shoot P concentrations varied over time in wheat grown soils amended with C1, C3 and C4, but not in wheat grown in the unamended soil and soil amended with C2 (Fig. 4a). Shoot P concentrations were higher in wheat grown in soil sampled after 18 months than that sampled after 2 months in soils amended with C1, C3 and C4. Compared to the unamended soil, addition of C3 and C4 increased shoot P concentrations from the sampling at 4 months onwards and addition of C1 from 13 months onwards. Wheat grown in soil amended with C2 had either lower or similar P concentrations than wheat grown in the unamended soil. There were positive correlation between shoot P concentration and available P and total P concentrations in the compost (r^2=0.71 and 0.50, P < 0.001).

Shoot N concentrations were highest in wheat grown in the soil sampled after 6 months and then decreased (Fig. 4b). Shoot N concentrations were highest in wheat grown in soil amended with C4 where they were up to 4 fold higher than in wheat grown in the unamended soil, followed by C3 and C1. Addition of C2 had no effect on shoot N concentrations or decreased them compared to wheat grown in the unamended soil. There was a positive correlation between shoot N concentrations and concentrations of available and total N in the compost ($r^2 = 0.94$ and 0.99, $P < 0.001$).

Discussion

This study showed that composts differed in their effect on soil properties and plant growth in the bioassay and that this effect changed over time. The coarse-textured compost had the least effect on soil properties and plant growth. Application of the other composts resulted in increased N and P availability, but this was due to different processes: release of N and P already present in available form in the compost at the time of application or mobilisation of N and P during the course of the experiment.

Compost application had little effect on total and dissolved organic C (Table 2), pH and EC in the soil. This may be due to the application method as the composts were added as mulch, not incorporated. Further, rainfall will have leached dissolved and possibly even particulate organic matter and salts from the pots (Kaschl *et al.* 2002; McCracken *et al.* 2002; Poll *et al.* 2008). Emmerling *et al.* (2009) and Wright *et al.* (2007) also found total organic C content was not affected by compost application more than 2 years after compost application. The increase in soil pH by C1, C2 and C4 could be due to ammonification of compost-derived N and the presence of Ca and Mg in the composts which may release H^+ from exchange site and subsequent leaching of protons (Bolan and Hedley 2003; Odlare *et al.* 2008; Ouedraogo *et al.* 2001; Poll *et al.* 2008).

The field capacity of the soil (data not shown) and aggregate stability were increased by C1, C3 and C4 (Figs. 1) but not by C2 and this occurred although the total organic C concentration was not different from the unamended soil. The increased aggregate stability and thus improved soil structure and water-holding capacity is therefore most likely due to microbial activity which was stimulated by the nutrients leached from the composts because bacterial slimes and fungal hyphae improve soil aggregation (Tisdall and Oades 1982) .

Composts 3 and 4 resulted in the highest concentrations of available P (Fig. 2a). However, the processes leading to the high P availability differed between the two composts. In C4, the high soil P availability can be explained the high P availability in the compost at the time of application. On the other hand, P availability was low in C3. However, this compost was characterised by a high total P concentration. Thus, P was mobilised during the experiment in this compost. Compost 1 also had a high total P concentration but did not increase P availability suggesting that little P was mineralised from this compost during the course of the experiment. The P immobilisation with C2 can be explained by its low total P concentration (Table 1).

The available N concentration was increased by C1, C3 and C4. With application of C1 and C3, the increase in available N was very rapid whereas it was slower with C4 (Fig. 2b). With C3, the rapid increase in available N can be explained by its high concentration of available N at the time of application. However, the available N concentration was low in C1, suggesting that N was rapidly mineralised in this compost after adding it to the soil. The increase in available N concentration in the soil was slower with C4 which had moderate concentrations of available and total N. Thus, in this compost, N mineralisation was slower than in C1.

Shoot biomass (Fig. 3) was highest in the soil sampled 4 months after compost application and lowest after 9 months which can be explained by the season in which the plants were grown: during spring after 4 months, during summer after 9 months (very hot conditions in the glasshouse). The high biomass after 4 months also coincided with high N availability. On the other hand, the concentrations of available N and P were also high after 13 and 18 months, but this did not result in high shoot biomass. At these sampling times, the soil in the pots had been exposed to more than a year of rainfall which would have caused the soil to settle thus increasing its bulk density compared to the looser soil at the start of the experiment.

The shoot P concentration indicates that the plants were not P deficient. The shoot P concentrations were related to the concentration of available P in the soil, being highest at the end of the experiment and with C3 and C4 (Fig. 4a).

The shoot N concentrations peaked at 6 months, coinciding with high soil N availability, but shoot biomass was greatest after 4 months (Fig. 4b). Thus the high shoot N concentrations after 6 months are probably due to two factors: low biomass and high soil N availability. The high biomass after 4 months would, on the other hand, resulted in dilution and thus lower N concentrations (Choi and Chang 2005; Nieder *et al.* 2011). Shoot N concentrations were highest with C4 although available N concentrations were lower than with C1 and C3. However, shoot biomass and therefore probably also root biomass were highest with C4, thus the plants were able to access a greater soil volume and take up N. Further, P availability was highest with C4.

The effect of the composts and the relationship to their properties can be summarised as follows:

Compost 1 had a fine texture and high total N concentration but a low concentration of available N. The high N availability with this compost can be explained by mineralisation of compost N during the experiment which was aided by the fine texture of this compost. However this compost supplied little P to the plants as it was low in total and available P.

Compost 2 resulted in N and P immobilisation and did not increase plant growth compared to the unamended soil. This can be explained by the coarse texture and the low concentrations of total N and P of this compost all of which would retard decomposition. The low N and P availability in the soil and to the plants occurred although N and P availability in the compost were moderate to high. This suggests that N and P were immobilised in the compost and not transferred into the underlying soil.

Application of C3 resulted in high N and P availability which can be explained by the high concentrations of available N in the compost on the one hand and mineralisation of compost P during the experiment on the other.

Plant growth and N and P availability were highest with C4 which had the highest concentrations of available P and medium concentrations of available and total N. Thus in contrast to C3, N would have been mineralised in the compost during the experiment whereas P may have been directly transferred into the soil without the need for mineralisation during the experiment. Further, this compost had the highest germination index indicating it contained the least inhibiting compounds among the composts.

Conclusion

This study showed that the effect of composts applied as mulch on soil nutrient availability and plant growth varies with time and compost type. Coarse-textured composts with low total N and P have little effect on soil properties and plant growth, even 18 months after application. With the medium and fine textured composts, N and P availability increased over time whereas plant growth was maximal a few months after compost application suggesting that plants may have been less able to take up nutrients in the later stages of the experiment because of soil compaction. The effects of the composts on nutrient availability is a function of two mechanisms: (i) N and P already present in the compost in available forms leaching into the underlying soil, and (ii) mobilisation of N and P in the compost over time with the rate of mobilisation varying with compost type.

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Table 1 Chemical and physical properties of the four composts (C1, C2, C3 and C4)

	Unit	C1	C2	C3	C4
pH		8.1	6.3	7.1	8.6
EC	dS m^{-1}	4.2	1.0	7.5	0.8
Bulk density	g cm^{3-1}	0.54	0.44	0.56	0.49
Water content	g g^{-1}	0.46	1.04	0.47	0.87
Resin P	mg kg^{-1}	9.7	19.1	5.2	364.9
Total P	g kg^{-1}	2.19	0.20	4.69	1.66
TOC	%	17.8	29.0	11.8	11.9
Available N	mg kg^{-1}	6.6	99.6	140.2	32.5
Total N	g kg^{-1}	18.3	8.2	9.6	11.0
Dissolved organic C	mg kg^{-1}	39.4	17.7	31.0	30.7
Germination index	%	80.2	67.6	61.3	90.3
Particle size	%				
4.75-3.25 mm		26.6	35.0	34.2	37.0
2-1 mm		40.8	56.0	53.0	45.6
0.5-0.25 mm		32.6	8.9	12.8	17.4

Table 2 Soil dissolved organic C (mg kg^{-1}) with no compost or amended with four different composts (C1, C2, C3 and C4) over 18 months (n=4).

Dissolved organic C (mg kg^{-1})					
Sampling dates	Treatments				
(Months)	**C1**	**C2**	**C3**	**C4**	**Unamended soil**
Day 0					
1.37					
2	2.19	1.59	1.97	2.20	1.36
4	2.36	1.66	2.38	2.36	1.54
6	2.09	2.53	2.03	2.55	1.47
9	2.16	1.47	1.84	2.37	1.20
13	2.10	1.32	2.18	2.51	0.92
18	1.89	1.60	1.68	2.19	1.50
L.s.d.	**0.45**				

List of Figures

Figure 1 Water-stable aggregates >1 mm and <1mm after 18 months in soil without compost or amended with four different composts (C1, C2, C3 and C4).* indicates significant difference to the unamended soil.

Figure 2 Soil available P (**a**) and N (**b**) concentrations without compost or amended with four different composts (C1, C2, C3 and C4) over 18 months (n=4). The vertical line indicates the lsd.

Figure 3 Shoot dry matter of wheat grown for 4 weeks in soils sampled 2-18 months after amendment with four different composts (C1, C2, C3 and C4) and the unamended soil (n=4). The vertical line indicates the lsd.

Figure 4 Shoot P (**a**) and N (**b**) concentrations of wheat grown for 4 weeks in soils sampled 2-18 months after amendment with four different composts (C1, C2, C3 and C4) and the unamended soil (n=4). The vertical line indicates the lsd.

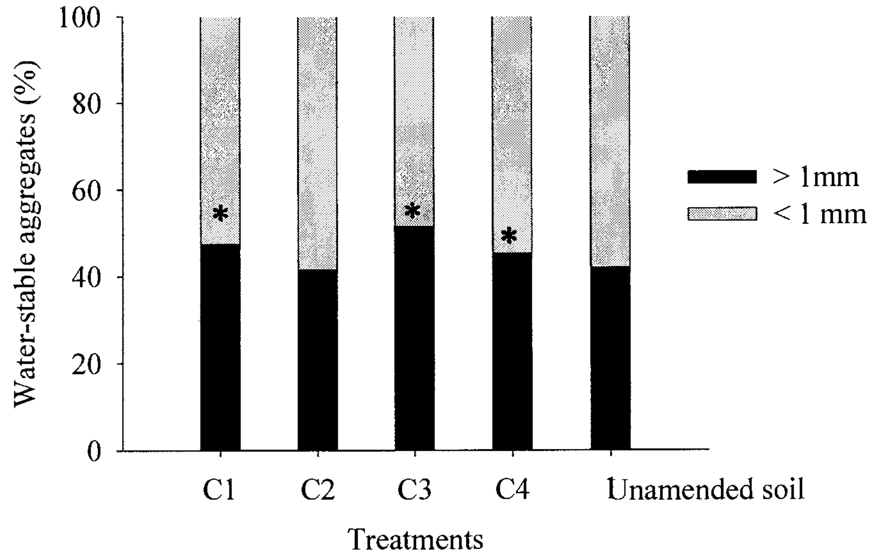

100
80
60
40
20
0
Water-stable aggregates (%)
*
*
*
> 1mm
< 1 mm
C1
C2
C3
C4
Unamended soil
Treatments

Figure 1

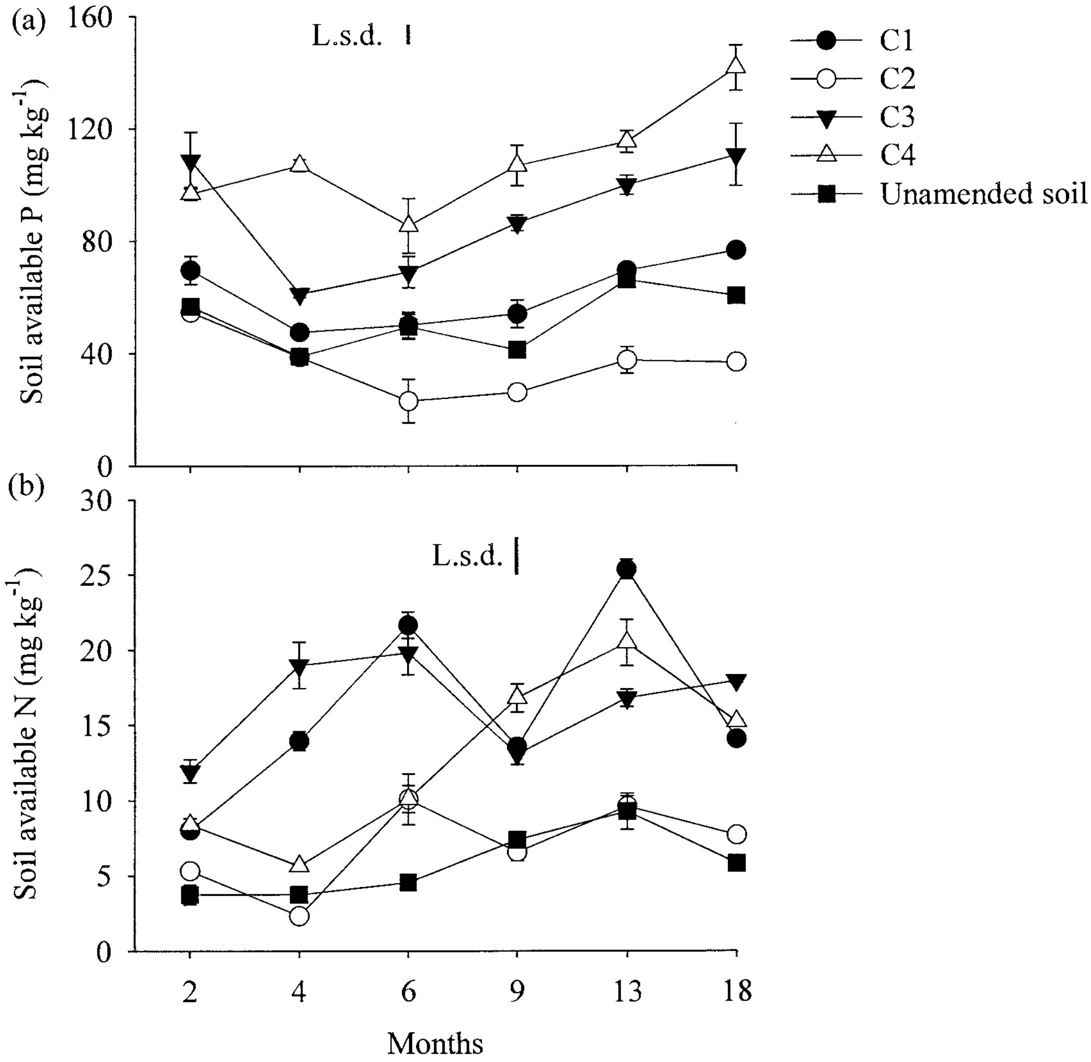
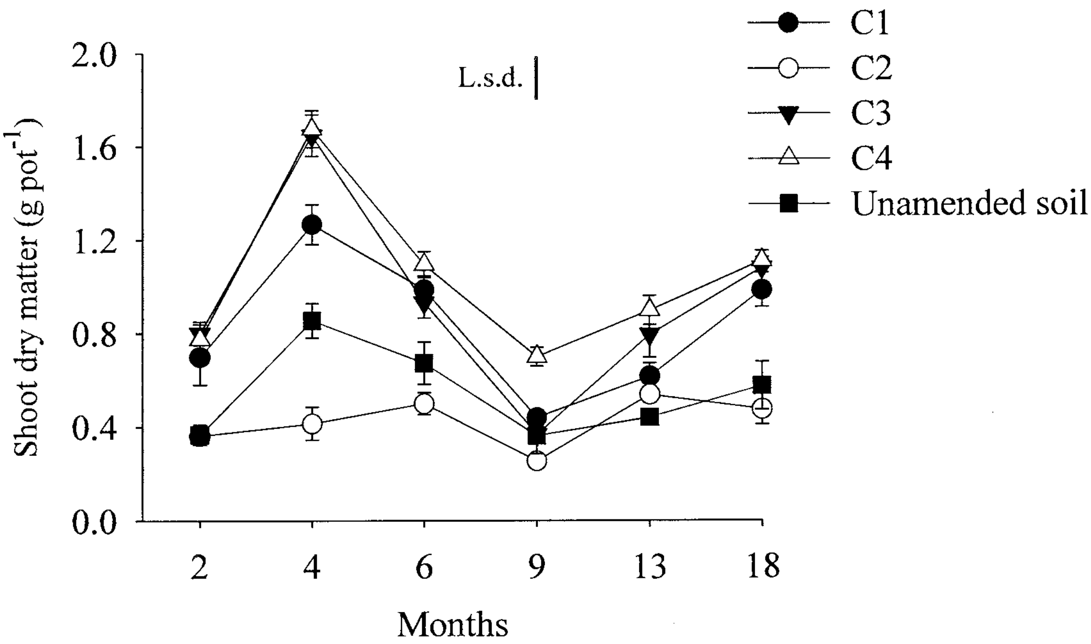


Figure 2 (**a**) and (**b**)



C1
C2
C3
C4
Unamended soil
L.s.d.
Shoot dry matter (g pot^{-1})
2.0
1.6
1.2
0.8
0.4
0.0
2
4
6
9
13
18
Months

Figure 3

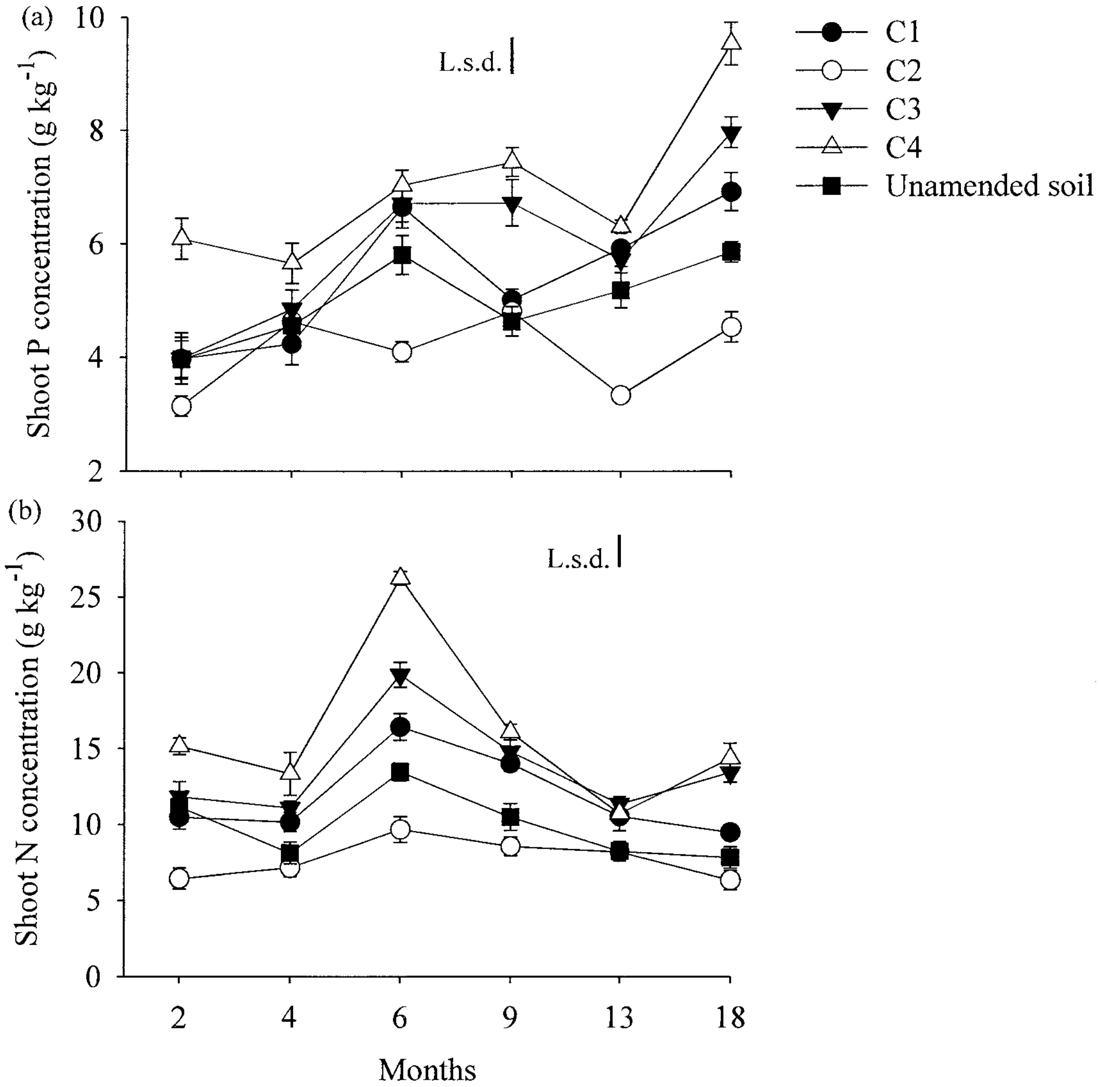


Figure 4 **(a)** and **(b)**

Chapter 3

Differential effects of composts on properties of soils with different textures

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Chapter 4

Amending soils of different texture with six compost types: impact on soil nutrient availability, plant growth and nutrient uptake

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Chapter 5

Nutrient release from composts into the surrounding soil

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Chapter 6

Conclusions and Future Research

Conclusions

Intensive cultivation, misuse and excessive use of chemical fertilisers may lead to loss of soil organic matter, have adverse effects on the environment and can threaten human and animal health as well as in food safety and quality. Fertilisers are needed for high yields, particularly in nutrient-poor soils. With increasing fertiliser prices and limited resource reserves, organic amendments such as composts, manures or plant residues as sources of nutrients and organic matter are considered an economic and environmentally-friendly alternatives. Compared to plant residues and manure, composts release nutrients more slowly and have longer-lasting effects (Bernal et al., 2009; Sanchez-Mondero et al., 2004; Tejada et al., 2008). The slow decomposition is more effective increasing soil organic matter content of the soil which plays a key role in soil fertility by retaining nutrients, maintaining soil structure, and holding water (Rashad et al., 2011; Ros et al., 2006; Zameer et al., 2010). They also have additional advantages such as disposal and recycling of municipal solid wastes thereby reducing material going into landfill. .

Beneficial effects of compost application on soils have been well-documented such as increasing soil structural stability (Annabi et al., 2007; Barral et al., 2009), improving water holding capacity and plant water availability, decreasing leaching of nutrients (CIWMB, 2004; Curtis et al., 2005; Farrell et al., 2009), and reducing erosion and evaporation (Arthur et al., 2010; Gershuny, 1994). However, the effect of composts on soils is likely to be strongly dependent on compost composition which depends on feedstocks, composting conditions and duration (Bernal et al., 2009; Bueno et al., 2008; Cayuela et al., 2009). In addition, some studies have indicated that the effects of compost application on soil and plant properties may be modulated by soil type (Bustamante et al., 2010; Kawasaki et al., 2008; Messiha et al., 2009). However there are no systematic studies in which the effect of compost type and soil type on compost effects on soils and plants has been studied under controlled conditions.

The research presented in this thesis addressed the following knowledge gaps: (i) medium-term changes in nutrient release from composts, (ii) the influence of compost composition on the effect of compost on soil properties and plant growth, how this is modulated by soil type and (iii) changes in nutrient availability in immediate vicinity of the composts. It should be noted that in all experiments, the composts were applied as mulch which is common in horticulture. Compared to incorporation, this may have reduced the effect of the composts on soils and plants.

In the first study on medium-term changes in nutrient availability, four composts from various feedstocks (municipal solid waste, manure and straw-manure mixture) were applied once as mulch layer on the soil surface to a sandy loam and their effects on soil nutrient changes, plant growth and nutrient uptake studied after 2, 4, 6, 9, 13 and 18 months (Chapter 2). The results showed that nutrient availability in the underlying soil changed over time, with the highest concentrations of plant available N and P after 18 months whereas growth of the bioassay plant (wheat) was greatest after 4 months. The coarse-textured compost had a smaller effect on nutrient availability and plant growth than the finer-textured composts. Although the mulched composts did not increase soil organic matter content, the increased soil aggregation was probably due to the leaching of soluble nutrients into the soil which stimulated microbial activity and thus production of slimes and hyphae.

To assess how the effect of compost application is modulated by soil type, an experiment with three soil types, differing on clay content (13, 22 and 46 %) amended with two composts from different feedstocks (from garden waste and from agricultural residues and manures) was carried out over 77 days in the presence of wheat plants.

Some effects of compost amendment occurred irrespective of soil types such as increased plant growth, nutrient availability, concentration of dissolved organic C and microbial activity, but the magnitude of the effects differed among the soils, with smaller effects in the coarse textured soil. Compared to the soil type effects, the differences between the two composts were small. Nevertheless, the finer-textured compost had a greater effect than the coarse textured composts confirming the results of the medium-term study.

To better assess the effect of compost composition on soil properties and plant growth, six composts from different feedstocks were applied to two soils (13 and 46 % clay) and wheat was grown until grain filling (Chapter 4). In agreement with the first two studies, the finer-textured composts had greater effects than the coarse-textured composts on soil and plant properties suggesting that compost particle size and thus surface area-to-volume ratio is one of the governing properties driving the extent of leaching, accessibility to microbes, nutrient mineralization and mobilisation rates. This suggests that compost particle size plays a key role in the impact of compost on soils whereas compost nutrient concentration is less important. However, in contrast to the second study (Chapter 3), the effect of a given compost differed little between soils which may be related to the greater range of compost properties used in this experiment.

In the last experiment with three composts (Chapter 5), changes in nutrient concentrations were measured up to 10 mm from the compost layer. The composts induced higher microbial biomass and activity, total organic C and available N and P concentrations up to 10 mm into the surrounding soil with greater effects after 30 than after 63 days. In agreement with the previous studies, the increase in nutrient concentrations were generally greater in soil adjacent to the two composts which had a fine texture and higher nutrient concentration than in the coarser-textured compost with lower nutrient concentrations, however the differences in nutrient concentrations in the soil were small compared to those in the composts.

Contribution to knowledge

These studies highlight the importance of compost particle size on nutrient release. Finer-textured composts have a greater surface area-to-volume ratio which increases decomposition rate and also leaching of nutrients. On the other hand, the relationship between N and P concentration in the composts and nutrient availability in the underlying soil were more complex. High nutrient availability in the soil could be explained by two mechanisms: (i) release of N and P already present in available form in the compost and (ii) mobilization of N and P during the experiments which varied with compost types.

The results suggest that fine-textured composts can replace inorganic fertilizers to some extent, but would have to be applied every 1-2 years to maintain high nutrient availability. However, the changes in nutrient release from the composts over time may make optimisation with the nutrient demand of the crop difficult. Thus, supplementation with inorganic fertilizers may be required. Composts with high concentrations of available N and P would need to be applied with caution to prevent leaching of these nutrients.

Applied as a mulch, most composts improved soil structural stability at least in the short- to medium term which is probably related to nutrients (C, N and P) leaching from the composts into the underlying soil increasing microbial activity.

The effects of composts on soil properties and plant growth are likely to be greater when the compost is incorporated in the soil instead of being applied as mulch. When mixed into the soil, the compost would be more accessible to soil microbes and also to plant roots. On the other hand, the higher decomposition rate may shorten the time during which composts have an effect on soils.

Recommendations for future research

The studies presented in this thesis provided further insights in the effect of composts on soils and plant growth as well as into the underlying mechanisms. But many gaps in the understanding remain, some which could be addressed in the following way:

- To better assess the contribution of particles of different sizes in a compost on soil properties and plant growth, a compost could be divided into different particle size classes which would be applied separately.
- To understand the effect of the compost application method, the compost effect should be compared after addition as mulch or incorporation.

- The long-term effect of a single compost application could be tested by taking soils of similar texture with known history of compost application (e.g. 1, 2, 3, 5 years ago) and conducting similar pot experiments as described here.
- The potential for nutrient leaching from composts could be assessed by leaching composts repeatedly with water and measuring C, N and P in the leachate.
- Field experiments would need to be carried out to assess the effect of composts in varying climatic conditions and on different crops.

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