Objective 3

A review of the effects of uncomposted materials, composts and manures on soil health and quality, soil fertility, crop development and nutrition

Contents

3.1. Introduction
3.1.1. Soil health
3.1.2. Soil fertility in organic farming
3.1.3. Crop development and nutrition in organic farming
3.1.4. Scope of literature

3.2. Effects on soil health, quality and fertility
3.2.1. Soil organic matter
3.2.2. Biological properties
3.2.3. Chemical properties
3.2.3.1. pH
3.2.3.2. N
3.2.3.3. P
3.2.3.4. K
3.2.3.5. Other elements
3.2.3.6. Electrical conductivity
3.2.3.7 Cation Exchange Capacity
3.2.4. Physical properties
3.2.4.1. Water holding capacity and porosity
3.2.4.2. Bulk density/Penetration resistance
3.2.4.3. Aggregate stability

3.3. Potential environmental impacts
3.3.1. Nitrate leaching
3.3.2. Runoff and erosion
3.3.3. Gaseous losses
3.3.4. Human pathogens
3.3.5. Potentially toxic elements (PTE's)

3.4 Crop development and nutrition
3.4.1 Yield
3.4.2 Crop nutrition
3.4.3. Product quality
3.4.4. Plant health

3.5 Tools and models for compost application

3.6 Systems aspects

3.7 Conclusions
3.7.1 General conclusions
3.7.2 Specific conclusions

Objective 3

A review of the effects of uncomposted materials, composts and manures on soil health and quality, soil fertility, crop development and nutrition

3.1. Introduction

3.1.1. Soil health

Soil health is central to organic farming, but it's potential hasn't been fully explored. At it's heart is the idea of soil as living dynamic organism that functions in a holistic way depending upon its condition or state. It also allows comparisons to be drawn with our own health; phrases such as soil sickness, feeding the soil etc take on a real meaning when soil is managed and treated as a vital living system.

Soil health has been formally defined as "the capacity of a specific kind of soil to function as a vital living system, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation."

3.1.2. Soil fertility in organic farming

Soil fertility is fundamental in determining the productivity of all farming systems. Soil fertility is most commonly defined in terms of the ability of a soil to supply nutrients to crops. Wild (1993) defines it as the ability of soil to produce crops. Similarly, Swift and Palm (2000) suggest that it is helpful to view soil fertility as an ecosystem concept integrating the diverse soil functions, including nutrient supply, which promote plant production. This broader definition is appropriate to organic farming, as organic farming recognises the complex relationships that exist between different system components and that the sustainability of the system is dependent upon the functioning of a whole integrated and inter-related system (Atkinson and Watson 2000).

Organic farming systems rely on the management of soil organic matter to enhance the chemical, biological, and physical properties of the soil, in order to optimise crop production. This subject has recently been reviewed by Watson *et al.* (2002a). Soil management controls the supply of nutrients to crops, and subsequently to livestock and humans. In addition to symbiotic N fixation and atmospheric deposition, nutrients may be brought in to the organic system in imported animal feeds, manures, composts and permitted fertilisers, such as rock phosphate (UKROFS 2001). The nature and quantity of imported nutrients will depend on the system and the soil type. Watson *et al.* (2002b) highlight the reliance on purchased manure in organic horticultural systems.

3.1.3. Crop development and nutrition in organic farming

Conventional agriculture frequently relies on targeted short-term solutions to solve nutritional problems e.g. application of a soluble fertiliser. In contrast, organic systems use a strategically different approach, which relies on longer-term solutions (preventative rather than reactive) at the systems level. An example of this is the importance of rotation design for nutrient cycling and conservation as well as weed, pest and disease control (Stockdale *et al*., 2001).

Yields of arable crops under organic management vary from as little as 50% to more than 95% of those in conventional agriculture (Lampkin and Measures 2001, SAC 2002). In relative terms, spring cereals perform better than winter cereals in organic systems. The yield penalty associated with organic production of crops such as wheat and barley, which have been bred intensively, is greater than for crops such as oats and triticale, which have undergone relatively little selective breeding. The large shortfall in cereal yields is linked to the difficulty of managing soils to synchronise N mineralization with the period of maximum N demand (Stockdale *et al.,* 1992). Most European studies of organic farming report lower crop yields in organic than conventional systems. In contrast, some American studies have reported similar yields in organic systems e.g. Poudel *et al.* (2002) for tomatoes and corn and Reganold *et al.* (2001) for apples.

The Soil Association (2000) carried out a comprehensive review of food quality in organic farming and summarised the findings of 29 studies which met their criteria on sufficient duration (i.e. fully converted to organic), correct organic practices, relevant comparisons and first publication of information. Of these studies 10 showed organic produce had higher dry matter contents than conventional produce, 7 showed higher mineral contents and 7 showed higher Vitamin C content. Protein contents of organic wheat are almost always lower than conventionally grown wheat (Starling and Richards, 1993). Gooding *et al.* (1997) in variety trials of bread-making varieties of winter wheat measured crude protein between 8.4 and 9.6% and Hagberg Falling Numbers between 200 and 320. Higher protein levels are often reported for spring wheat although these were still often below the 10.5% crude protein target for milling (Cormack, 1997).

Thus it is clear that in the future organic farming must strive towards improved crop yields and quality. While some aspects of this are associated with the need for plant breeding to develop varieties suited to organic conditions, crop nutrition remains a major challenge. Sanchez et al. (2001) suggests that the key to increasing the capacity of the soil to supply N to a growing crop is the addition of a diverse range of substrates to the farming system. Improved management of manures and composts has the potential to improve crop nutrition in organic farming.

<u>3.1.4. Scope of literature</u>

There is a very large literature relating to the influence of composted materials on soils and crops. Not all of it is relevant to organic agriculture for a number of reasons.

(a) In many cases the composts have been supplemented with fertilizers not approved for use in organic farming, for example, Manna *et al.* (2001) and Marchesini *et al.* (1988). Supplementing composts with rock phosphate is however of interest in organic farming.

(b) Not all the types of compost based on urban wastes in the literature are allowed within the organic standards. We have made the assumption that organic farming will over time revise the standards and that this review may be used to inform future decision making.

(c) Manures from organic farming systems usually have lower average nutrient contents than manures from conventional systems (Dewes and Hünsche 1998, Shepherd *et al.* 1999)

(d) In the literature, composts made from livestock manures are not always from livestock systems acceptable within organic farming. We have assumed that it is important to use this information to inform the development of organic farming. If we restricted sources to organically acceptable livestock systems this would be a much shorter review!

In reviewing the literature it is also obvious that care must be taken in using the results of older literature on municipal waste and sewage sludge. Manufacturing processes together with source separation have changed the chemical composition of many waste materials. For example, Purves and McKenzie (1974) refer to problems of B toxicity associated with paper waste. Paper waste no longer contains high levels of B (Epstein, 1997). The same applies to residues of deregistered pesticides, although some persistent chlorinated hydrocarbons may still be an issue.

Another difficulty in interpreting the literature is the basis on which comparisons have been made. Sometimes yield or nutritional responses have been based on different composts applied at the same rate, on other occasions different composts applied at different rates, In some cases, application rate has been determined on the basis of predicted N availability, in other cases commercial rates have been used.

3.2. Effect on soil health, quality and fertility

3.2.1 Soil organic matter

The benefits of increased soil organic matter content in terms of crop yield and nutrient uptake have been demonstrated by the long-term experiments at Rothamsted (Johnston, 1986). A literature review by McConnell *et al.* (1993) reported that compost applied at rates varying from 18 to 146 t ha^{-1} produced a 6 to 163% increase in soil organic matter. A more recent study by Zebarth *et al.* (1999) over a three-year period showed increases in soil organic matter from 5 different organic sources including biosolids, food waste and composted pig manure.

Effects on soil organic matter will differ between one-off and regular applications. The long-term experiments at Rothamsted demonstrate the build up of organic matter over time. For example, the Woburn Market Garden Experiment showed increases in percent C from 0.87% to 1.46 % from FYM additions and 2 % from composted FYM additions over a 25 year period (Johnston *et al.*, 1989). Vitosh *et al.* (1973) calculated that applying fresh cattle manure at 67.2 Mg ha^{-1} yr^{-1} increased the organic matter content of a sandy loam soils by 0.1% each year.

The effects of manure and compost use on C sequestration are of interest in relation to the ability of agriculture to contribute to meeting the Kyoto protocol. Eghball (2002) reported that 25% applied manure C remained in the soil after a four year period compared with 36% applied compost C suggesting that compost may have greater benefits for C sequestration than manure.

3.2.2 Biological properties

The effects of composts and manures on soil biological properties are reviewed in Objective 4.

3.2.3 Chemical properties

3.2.3.1. pH

Lime is often added to composts for pathogen or acidity control (Barker 1997) thereby increasing the Ca content. The effect of compost on soil pH is likely to depend both on the initial pH of the compost and the soil pH. There are reports in the literature of composts both increasing and lowering the pH of soils, and others where no effect was measured (e.g. Bevacqua and Mellano 1994, Crecchio *et al.* 2001, Zebarth *et al.* 1999). Working in acid soils, Mokolobate and Haynes (2002) found that additions of organic residues increased the pH in the soil in the order poultry manure>filter cake>household compost>grass residues when the residues were added at the same rate. The response was in direct relationship to the pH of the materials themselves.

Manures have been demonstrated to lower the pH of alkaline soils (e.g. Chang *et al.* 1991). The effect of livestock manures on increasing the pH of acid soils has also been demonstrated frequently (e.g. Hue 1992, Whalen *et al.*, 2000, Baziramakenga *et al.,* 2001). Increasing pH is clearly valuable in these soils in terms of improving microelement availability and reducing the solubility of some toxic elements and it is interesting to consider whether in some circumstances livestock manure can substitute for lime application, thus making use of locally available resources.

3.2.3.2. N

Incorporated plant residues can be an important source of nutrients in organic farming. It is well documented that different quantities of N, P, K and minor nutrients are removed from, and returned to, the soil depending on the crop species concerned (e.g. Sylvester-Bradley, 1993). The quantity and quality of crop residues will clearly influence the build up of soil organic matter and the subsequent availability and timing of release of nutrients to following crops. Cereal straw, for example, contains only around 35 kg N ha^{-1} compared with more than 150 kg N ha^{-1} for some vegetable residues (Rahn *et al.* 1992, Jarvis *et al*. 1996). Plant residues also contain variable amounts of lignin and polyphenols, which influence decomposition and mineralization rates (Vanlauwe *et al.* 1997).

Incorporation of N rich, low C:N ratio residues of fresh plant material, manures or composts leads to rapid mineralization and a large rise in soil mineral N. Kirchmann (1985) suggest that at a C:N ratio of 15 or less mineralization occurs, above this N will be immobilized. Thus mineralization rates are usually greater from fresh material than composted material (Cooperband *et al.*, 2002, Hadas and Portnoy, 1997, Tyson and Cabrera, 1993). It has also been shown that in a given time period the proportion of total N mineralized is lower from composted residues, which generally have higher C:N ratios (Ekbladh, 1995, Kirchmann, 1989, Tyson and Cabrera, 1993). Residues with very high C:N ratios such as paper waste can lead to net immobilization of N in the short to medium term (e.g. Simard *et al.* 1998).

A number of edaphic, climatic and management factors influence mineralization rate in soils, these were reviewed by Jarvis *et al*. (1996). Egelkraut *et al.* (2000) investigated the relationship between soil texture and mineralization of N from both composted and fresh organic materials, in both cases mineralization was greater in sandy than clay soils.

The challenge for organic farming is to manage the use of composts and manures to synchronise supply and demand for N. This requires understanding of both N release kinetics from different materials and crop growth patterns. Stockdale and Rees (1995) showed that fresh poultry manure and slurry released N very quickly, compared with FYM, pig manure and sewage sludge where initial N release was slower but sustained over a longer time period. In the year of application, Cooperband *et al.* (2002) observed that nitrate released from composted poultry manure (composted for 1, 4 and 15 months) was 3-4 times lower than from raw poultry manure, and that available soil nitrate-N from composts was no greater than from an unfertilized control. Mixing residues of differing quality has the potential to synchronize mineralization with crop demands (Handayanto *et al*., 1997) although the practicalities of this on a farm scale are questionable.

It has been shown that soils which receive organic matter inputs on a regular basis generally have greater labile C pools and greater N supplying ability than soils which receive only mineral amendments (Gunapala and Scow, 1998).

3.2.3.3. P

With continued application of composts and manures soil P levels will increase (Sharpley and Rekolainen, 1997). In soils already high in P, addition of composts and manures carries with it a risk of P runoff. In a review of phosphorus management of organic manures, Smith *et al.* (1998) concluded that restricting topsoil extractable P levels to 70 mg l^{-1} should minimise the risks of unnecessary P enrichment and subsequent leaching.

Low nutrient wastes useful for C inputs e.g. paper sludge may be more valuable for crops if composted in a mixture with high nutrient wastes like poultry manure. For example, Baziramakenga *et al.* (2001) demonstrated that a composted mixture of paper sludge and poultry manure increased the extractable P and K in soils. The uses of lime as a manure amendment has been shown to decrease the solubility of P in poultry litter (Moore and Miller, 1994). Mixing rock phosphate with manures and composts is likely to be beneficial for phosphate availability in soil, since acids in the decaying organic matter will aid the dissolution of the rock. Furthermore, chelation of soluble aluminium and iron with organic matter will restrict phosphorus fixation in soil (Bohn *et al.*, 1979).

The effect of poultry litter compost of different maturities on soil P was examined by Cooperband *et al.* (2002). Immature composts (composted for 1 and 4 months) immobilized soil P in the year of application. Over a 2-year period following application, a linear relationship was shown between P added and available soil P, regardless of compost maturity. Eghball and Power (1999) and Gagnon and Simard (1999) found similar results suggesting that cumulative application rather than P source determined available P.

Experimental design often makes it difficult to assess the relative impacts of different composts on soil nutrients. In a trial comparing the effects of different composted materials and raw manure on yield at Rodale (Reider *et al*., 2000), application rates were designed to target specific amounts of available N. This resulted in widely differing extractable P and K levels and surpluses of P and K, in the different treatments.

3.2.3.4. K

In compost, K remains in water-soluble forms and thus does not need to be mineralised before becoming plant available. However, for the same reason it is at risk of leaching during the composting process and thus compost is often a poor source of K (Barker 1997). Composting of organic wastes does not appear to affect K availability but application may affect both soil K (Baziramakenga *et al.*, 2001, Wen *et al.* 1997, Warman and Cooper 2000a) and plant K uptake (Chen *et al.*, 1996).

Compost made from grass and straw has been shown to contain approximately twice the K content of chicken manure (Eklind *et al*., 1998). This type of material might therefore be beneficial in stockless organic systems

3.2.3.5. Other elements

One of the perceived benefits of the use of composts and manures over fertilisers is their ability to provide non-NPK nutrients. For example, Hue (1988) attributed increased crop yields from crops treated with sewage sludge compost rather than fertilizers to Ca and Mg supply. Studying a range of nutrients, Warman and Cooper (2000b) found that the effect of application of composted and non-composted poultry manure on soil nutrient levels was generally similar. However, Ca levels in the topsoil were significantly higher from the composted manure.

3.2.3.6. Electrical conductivity

Electrical conductivity is a measure of the salt concentration in the soil solution. Electrical conductivity has been shown to increase with increased manure/compost application rates (Chang *et al.*, 1991, Eghball, 2002). Shiralipour *et al.* (1992) reviewed the effects of municipal solid waste compost on soil properties and concluded that while municipal solid waste compost could induce salinity damage, the effects were likely to be much less than from sewage sludge applied at the same loading rate. Bevacqua and Mellano (1994) reported municipal compost causing salinity problems that could threaten the production of sensitive horticultural crops.

3.2.2.7. Cation Exchange Capacity
Cation Exchange Capacity (CEC) describes the ability of a soil to retain cations on soil colloids as a result of negative charges. CEC is thus important for retaining nutrients and making them available to plants. Soil organic matter and clay minerals are the two most important constituents that influence soil CEC. Thus increasing soil organic matter through compost addition is likely to increase CEC. McConnell *et al.* (1993) in a review of MSW compost concluded that applying compost at normal agronomic rates (38 to 75 Mg ha^{-1}) would increase the CEC of most mineral soils used for agriculture by a minimum of 10%. However, in a sandy soil in British Columbia, Zebarth et al. (1999) found CEC to be unaffected by a range of composted and non-composted organic amendments. In a pot experiment over a 7-year period Jakobsen (1996) found that on average CEC was reduced by mineral fertilizers but unchanged by compost amendments.

3.2.4 Physical properties

In relation to soil physical properties effects of organic matter additions vary with climate, soil type and texture and rate and type of organic matter addition. The latter is in agreement with the findings of Tisdall and Oades (1980) that quality is more important than quantity in relation to effects of organic matter on aggregate stability. It has also been observed that a greater quantity of organic material is needed to improve soil structural properties than is necessary to supply the nutrient requirements of a growing crop. Thus economic and environmental impact must be accounted for in quantifying the value of use of organic materials.

3.2.4.1. Water holding capacity and porosity
Increasing the water holding capacity of soils provides more available water to plants and can also help in resistance to drought. In a non-aggregated soil any effects on water retention are likely to be due to the properties of the compost material itself. However in a more structured soil changes in both aggregation and pore size and continuity may affect the water holding capacity. Baziramakenga *et al.* (2001), Chang *et al.* (1983), Giusquiani *et al.* (1995) and Hernando *et al.* (1989) have all found increased soil water holding capacity after application of urban wastes. Chang *et al.* (1983) also noted increased hydraulic conductivity. Edwards *et al.* (2000) found that compost made from a mixture of potatoes, sawdust and manure increased soil moisture over untreated soil. Urban waste compost has also been shown to increase total porosity (Aggelides and Londra 2000, Giusquiani *et al.*, 1995, Pagliai *et al.*, 1981). Porosity is a measure of the size and arrangement of voids in the soil matrix, and thus affects both aeration and water movement. In addition to increasing total porosity, compost application can change pore size distribution. Pagliai *et al.* (1981) observed an increase in the number of small and medium sized pores in compost amended soils, indicating a better structure and potential plant growth. Using thin sections Giusquiani *et al.* (1995) also found that stability of the pore system was improved in treated soils. They also observed that total porosity increased linearly with compost application rates.

3.2.4.2. Bulk density/Penetration resistance
Bazoffi *et al.* (1998) showed that urban refuse compost increased soil bulk density although Chang *et al.* (1983) and Giusquiani *et al.* (1995) found that bulk density was reduced by municipal sludge compost and urban waste compost respectively. Zebarth *et al.* (1999) applied six different organic amendments including biosolids and food waste compost and

found that all the materials reduced bulk density. A decrease in bulk density might be expected when soil is mixed with less dense organic material, but there may also be associated changes in soil structure (See section on aggregate stability). The magnitude of change for bulk density and other soil properties is likely to differ with soil texture as noted by Aggelides and Londra (2000).

Reduced penetration resistance as a result of compost use is also commonly reported (e.g. Aggelides and Londra 2000). Low soil penetrometer readings indicate more favourable conditions for root growth. Edwards *et al.* (2000) observed that compost decreased penetration resistance in the subsoil under potatoes, possible reflecting improved soil structure. Similarly, Bazzoffi *et al.* (1998) found that compost could prevent increased penetration resistance under heavy trafficking.

3.2.4.3. Aggregate stability

Many studies have addressed the effects of composts and manures on aggregate stability, although it is often difficult to compare results due to the use of different assessment methods (e.g. water stable aggregates or benzene stable aggregates) and also the information provided about application rates. Information on application rates is often presented as fresh weight Mg ha^{-1} but sometimes as N Mg ha^{-1}. Paper sludge has generally been shown to have a positive affect on aggregation (Gagnon *et al.*, 2001, Nemati *et al.*, 2000). Both Gagnon *et al.* (2001) and Nemati *et al.* (2000) compared composted and uncomposted paper sludge but found no difference in their effect on aggregation. Studies on the effect of sewage sludge and composted municipal wastes on aggregate stability have shown positive (e.g. Aggelides and Londra 2000, Albiach *et al.*, 2001, Pagliai *et al.*, 1981) and neutral effects (Guidi *et al.*, 1988). Effects may be limited in stable soils as in the study of Guidi *et al.* (1988). An interesting study by Paré *et al.* (1999) compared the effects of fresh and stockpiled cattle manure on aggregate stability. Using a method based on pre-treatment with ethanol, they separated the effects of the two manure types on stability against dissolution and disruptive forces (simulating chemical disruption) compared with resistance to slaking forces (simulating physical disruption). Fresh manure caused a decrease in stability against dissolution and disruptive forces compared with an untreated soil, whereas stockpiled manure did not affect this property. Fresh manure however caused a much greater improvement in resistance to slaking forces than stockpiled manure.

There is some evidence that the effect on aggregate stability is transient due to the natural decay of organic matter (Bazzoffi *et al.*, 1998). However, regular additions of organic matter will have long-term effects (Haynes and Naidu, 1998). Debosz *et al.* (2001) noted an instantaneous effect on aggregation of sewage sludge, where the effect of municipal compost was slower. They attribute this to the extracellular polymeric substances accumulated during anaerobic storage of sewage sludge.

The extraction of humic acids from composted wastes for use as commercial soil conditioners has also received some interest. Canarutto *et al.* (1996) found that microaggregation was improved by the addition of humates from green waste compost. Such substances are also known to have beneficial effects on plant growth and microbial populations so may be of interest in high value horticultural crops if economic methods of extraction can be developed. For use in organic farming systems, there would be a need to find out whether such materials are acceptable within the organic standards. This is likely to depend on both the original material and the method of extraction.

3.3. Potential environmental impacts

<u>3.3.1. Nitrate leaching</u>

In general nitrate leaching is controlled by the amount of excess nitrate accumulated in the soil above crop demand together with the drainage volume. In organic farming systems nitrate can accumulate from both added organic matter and mineralization of soil organic matter. Initial N content of the organic material is not a good indicator of the potential for leaching as the proportion of N in mineral and organic forms varies widely. Di and Cameron (2002) in a recent review of nitrate leaching in temperate agroecosystems report that mineral N contents (% total N) varied from 15% in anaerobic dairy sludge to 60-85% in pig slurry.

Timing of application of organic material can play a major part in determining leaching loss. In grass/ clover leys, four equal applications of dairy shed waste resulted in less than half the leaching when the same amount of N was applied in two applications, because N availability was less synchronised with pasture demand (Di and Cameron, 2002). Application method is another important issue in relation to environmental contamination from the use of organic wastes. In a laboratory experiment, Gove *et al.* (2002) compared the effects of surface and subsurface application of fresh and composted biosolids. Subsurface application increased the risk of P and metal leaching, but did not affect nitrate leaching.

Robust comparisons of leaching loss from composted and fresh material are not commonly reported. In a lysimeter experiment, Leclerc *et al.* (1995) used the concept of leaching/supply ratio to examine the effects of different organic amendments across a rotation. This ratio was lower for manure compost than for urban compost. Vervoort *et al.* (1998) found that nitrate leaching was lower from composted than fresh chicken manure. It may be possible to capitalise on the N immobilization capacity of high C:N ratio wastes. For example, Vinten *et al.* (1998) demonstrated a reduction in leaching from 177 to 94 kg N ha^{-1} yr^{-1} in intensive vegetable production from an application of 40 t ha^{-1} dry matter of paper mill waste.

3.3.2. Runoff and erosion

Working in highly unstable loess derived soils Bresson *et al.* (2001) demonstrated that Municipal Solid Waste compost could combat surface structure degradation, helping to combat both runoff and erosion losses. Ros *et al.* (2001) examined the ability of composted and non-composted municipal waste to reduce runoff and erosion in Mediterranean soils. While both treatments reduced runoff compared with unamended soil, compost had a significantly greater effect on reducing soil loss than the less stable material.

Loss of P in runoff from applied manures varies with manure type and crop. In a review paper, Sharpley and Rekolainen (1997) quote losses of between 1.9 and 17.1 % of applied P in manure lost in run-off. One of the difficulties of minimising this loss is inflexibility on the part of the farmer regarding application times; this still often results from lack of adequate storage facilities. Vervoort *et al.* (1998) found no difference in the levels of soluble P in runoff from composted and fresh chicken manure, suggesting that runoff was directly related to the amount of P added to soil. In a laboratory study, Sharpley and Moyer (2000) measured the release of dissolved inorganic and organic P from simulated rainfall events from a range of manures and slurries applied at the equivalent of 10 Mg ha^{-1}. Amongst the manures dissolved organic and inorganic P leached decreased in the order swine>poultry>dairy. Losses from manures (1925-4380 mg kg^{-1} material) were generally greater than from composts (1859-2918 mg kg^{-1} material) where leaching decreased in the order poultry litter>dairy compost>poultry compost.

3.3.3. Gaseous losses

Ammonia emissions from field applied manures are responsible for around 10% of ammonia emissions in Europe (ECETOC, 1994). In a recent review Sommer and Hutchings (2001) concluded that there is a complex relationship between ammonia emission rates from slurry and soil conditions, slurry composition and climate. Furthermore they conclude that less research has been carried out on solid or poultry manure but the same controls are likely to apply. In their review of mechanisms for reduction of ammonia loses they do not refer in detail to the effects of composting on ammonia loss following spreading. Losses of ammonia after application have, however, been shown to be much higher from manures stored anaerobically than aerobically as they contain a much higher proportion of ammonium (Pain *et al*., 1993). Ammonia loss from slurry also tends to decline with decreasing dry matter content partly due to increased infiltration rates (Sommer and Olesen, 1991). Brinson *et al.* (1994) compared ammonia volatilization from surface applied fresh and composted poultry manure under laboratory conditions. Cumulative ammonia loss over a 21day period ranged from 17-31% from fresh material compared with 0-0.24% from composted material. Application method such as applying slurry to ploughed land and incorporation of manures into arable land have been shown to reduce ammonia loss over surface application, as reviewed by Sommer and Hutchings (2001).

Annual nitrous oxide emissions have been shown to increase with manure rate (Chang *et al*., 1998). Kaiser *et al.* (1998) observed an inverse relationship between nitrous oxide emission and dry matter to N ratio of incorporated crop residues. However, few studies have compared annual nitrous oxide losses from field application of different organic materials. In a German study, Mogge *et al.* (1999) compared losses from slurry and FYM application to maize. In the FYM treatment 5.7% of applied N (equivalent to 5.3 kg ha^{-1}) was lost as nitrous oxide compared with only 0.6% of applied N in the slurry treatment (equivalent to 2.1 kg ha^{-1}). In a laboratory incubation experiment, addition of 30 Mg ha^{-1} household compost had no significant effect on cumulative nitrous oxide production compared with an unamended soil (De Wever *et al*., 2002). De Wever *et al*. (2002) thus concluded that the use of compost as a fertilizer at normal agronomic rates would not have much effect on nitrous oxide production. Contrasting results have been observed for sewage sludge in field trials. Scott *et al.* (2000) measured a cumulative loss of 23 kg N ha^{-1} from incorporated sewage sludge. High carbon dioxide losses of 5.1 Mg C ha^{-1} accompanied this loss.

<u>3.3.4. Human pathogens</u>

It has been suggested in the literature (e.g. Stephenson, 1997) that the use of manures and the non-use of some preservatives in organic food may mean an increased risk of microbial contamination of organic food. The organic standards, however, prevent the use of fresh manure and require good management practices in the storage and handling of manures and composts. Both composting of farmyard manure (Jones, 1982, Lung *et al*., 2001) and anaerobic digestion of slurry (Kearney *et al.*, 1993) have been shown to decrease pathogen viability. There have been a number of claims of *E. coli* (O157:H7) outbreaks being associated with organic food (e.g. Avery, 1998) but none of these claims have ever been proven. There does not appear to be any peer-reviewed literature showing that certified organic produce carries a higher risk of *E-coli* contamination than conventional produce. Research does however need to be carried out to establish the microbiological safety risks associated with different production systems.

In a review of pathogens in livestock waste Mawdsley *et al.* (1995) cite 11 bacteria, 3 viruses and 4 protozoa/parasites found in livestock waste which may cause human disease. Application of animal wastes to land can cause contamination of ground and surface waters with pathogenic organisms (McMurry *et al.*, 1998), which can then be transmitted to both livestock and humans. *E. coli*, and especially verocytotoxin producing *E.coli*, including serogroup O157 is excreted by as much as 15.7% cattle in the UK (Chapman *et al.*, 1997).

Vinten *et al.* (2002) demonstrated that the first drain flows after slurry application led to very high E. coli concentration in field drains, but low level contamination persisted for 3 months. Epstein (1997) quotes a review by Sorber and Moore (1986) summarising data on survival of microorganisms form biosolids applied to soil. The median die-off rate (days, 99%) was 155 for total coliforms in the top 5 cm of soil, and 22 and 30 days for Salmonella in the 0-5 cm and 5-15 cm soil layers.

3.3.5. Potentially toxic elements (PTE's)

PTE's are not only a potential problem in urban wastes but also in animal manures where metals are present in the diet e.g. Cu in pig and poultry diets. Some fungicides contain Cu, Zn or Mg and their residues may remain on composted organic matter (Graham and Webb, 1991). This potential toxicity must be considered from a food chain perspective taking into account toxicity to animals and humans as well as plants and soil. Application rate is key here, and there are many examples in the literature of experiments being carried out at application rates which are not agronomically justifiable. Metals released from decomposing organic matter may become available for plant uptake, but it is not always possible to predict this from chemical extractions. For example, Arnesen and Singh (1998) found that application of compost increased plant Cu levels but not DTPA extractable Cu but the reverse was true for Zn. Soil type is also important as it will in part determine the availability of toxic as well as nutrient elements to soils. This depends on the leaching/adsorption properties of the soil that will be strongly related to pH, texture and organic matter content. Warman and Cooper (2000b) have demonstrated this mediating effect of soil following poultry manure application where despite significant Cu levels in the material, extractable Cu was no higher in manure treated plots than in control plots.

From a review of 96 articles on phytotoxicity caused by metals from municipal solid wastes, Woodbury (1992) concluded that plant uptake of Cu, Ni, Zn, As and Pb was likely to be slight. He remarked that although levels would accumulate in soil over time, there may occasionally be problems with B. As noted earlier, introduction of modern manufacturing processes together with source separation are changing the chemical composition of many waste materials, and the use of older literature reports may overstate possible toxic effects. Regulation also limits the application rate of PTE's from sewage sludge. Giusquiani *et al.* (1995) found that total heavy metals in soil accumulated in proportion to the rate of urban waste compost added, unfortunately no mention of extractable levels is made in that study. Baziramakenga *et al.* (2001) found increases in available Mn and Zn following application of mixed compost of paper sludge and chicken manure.

Working in acid soils, Mokolobate and Haynes (2002) found that additions of organic residues decreased exchangeable Al in the soil in the order poultry manure>filter cake>household compost>grass residues when the residues were added at the same rate. The mechanisms for this were suggested to be due to high $CaCO_3$ content in the case of poultry manure and filter cake, the proton consumption capacity of humic material present in the household waste and decarboxylation of organic acid anions during decomposition of the grass residues.

3.4 Crop development and nutrition

3.4.1 Yield

There is a vast literature available on the effects of composts and manures on yields of agricultural and horticultural crops. There are relatively few reports in the literature of the effect of compost on yield in organic farming systems. Table 4a indicates the scope of the literature and highlights the fact that there is an interaction between crop and compost type. For example, Van Assche and Uyttebroecke (1982) found that domestic compost increased the yield of celery but not lettuce. There are also reports of positive, negative and neutral effects of different composts on the same crop e.g. barley (Lobo, 1988, MacLeod *et al.*, 2000). Eriksen *et al.* (1999) found no increase in yield with rates of up to 189 Mg ha^{-1} MSW compost. However, in the following cereal rye cover crop yield and N content increased linearly with application rate. This suggests a need to look at compost application over more than one growing season.

There are some reports in the literature of the effect of compost maturity on yield. For example, Cooperband *et al.* (2002) found that yield of corn was higher from raw poultry manure applied at 8.9 Mg ha^{-1} than from 1, 4 and 15 month old composts applied at approximately 60 Mg ha^{-1}. There are very few reports of comparisons between raw and composted materials in organic systems. In an organically managed field trial at Rodale over a three-year period, yield of corn was always higher in a raw dairy manure treatment compared with a compost of dairy manure and leaves (Reider *et al*., 2000). Oats and pepper yields were similar in both treatments. However, these results must be interpreted with caution as they compare treatments with application rates designed to supply the same amount of N. Three years of field trials of compost use on a UK organic farm (HDRA, 2001) were unable to distinguish effects of compost on crop yields because the effect of the compost was confounded by other fertility management treatments.

Many comparisons between different materials are difficult to generalise from. For example, Båth and Rämert (2000) compared the effects of slurry, household compost and chicken manure on leek production. The inorganic N content of the three products was 84, 2 and 11 kg ha^{-1} respectively. Unsurprisingly the fresh weight of leeks produced was up to 20 Mg ha^{-1} greater from the slurry treatment.

3.4.2. Crop nutrition

The immediate fertilizer N value of a manure or compost can be calculated from its inorganic content plus the readily mineralizable fraction. In a study using composted livestock waste pellets, Yan *et al.* (2002) found that in 3 months after application, dairy cattle, swine and poultry manure pellets released 31.5, 41.6 and 51.3 % of N. However, there is also a longer-term aspect to nutrient supply from organic materials regarding both the initial inorganic N content of the material and the longer-term mineralization of organic N over several years. Much research has focused on developing decay series that attempt to predict the proportion of added N available over a number of years (e.g. Klausner *et al.*, 1994).

Information on the effects of manures and composts on crop nutrition in organic systems is still limited, although more is now becoming available. In an organic system at Rodale with organic matter application rates balanced to provide similar amounts of available N, corn grain produced with raw dairy manure had a higher N content than grain produced with composted manure (Reider *et al.*, 2000).

One of the challenges for sustainable use of manures and composts is that manure or compost application to provide N may over supply P. This is because the N/P ratio of manures and composts is significantly smaller than the N/P uptake ratio of most crops (Eghball, 2002). Compost maturity affects crop nutrient uptake, for example, Cooperband *et al.* (2002) observed higher P uptake from mature and raw poultry manure than from immature composts that caused P immobilisation in soil. By contrast, for potassium, Wen *et al.* (1997) found that K in organic wastes is as available as it is in mineral fertilizers.

Table 4a Effect of various composts on cereal and vegetable crop yields

Crop	Compost	Effect on yield	Reference
Barley	Municipal waste	0	MacLeod *et al.* (2000)
	Vine shoot compost	-	Lobo (1988)
	Vine shoot compost + pig slurry	+	Lobo (1988)
	Composted paper sludge	+	Vagstad *et al.* (2001)
Maize	Composted domestic waste	+	Movahedi Naeini and Cook (2000)
	Composted poultry litter	+	Cooperband *et al.* (2002)
Wheat	Mixed biosolids and manure	+	Fauci *et al.* (1999)
	Composted paper sludge	+	Vagstad *et al.* (2001)
Broccoli	Mixed green waste and cow manure	0	Stamatiadis *et al.* (19990
Celery	Domestic waste compost	+	Van Assche and Uyttebroecke (1982)
Lettuce	Sewage sludge compost	+	Bevacqua and Mellano (1994)
	Domestic waste compost	–	Van Assche and Uyttebroecke (1982)
Onion	Sewage sludge compost	+	Bevacqua and Mellano (1994)
Potatoes	Deinking paper residues and poultry manure	+	Baziramakenga and Simard (2001)
	Mixed potatoes, manure and sawdust	0	Edwards *et al.* (2000)
	Municipal compost	+	Purves and McKenzie (1974)

Organic materials are often valued for the addition of minor elements to soils at no extra cost. In organic systems they are essential for both recycling nutrient within the farming system and replacing nutrients sold in produce. Most studies of crop uptake from organic materials have focused on N, P, K and/or PTE uptake. Garcia *et al.* (1991) observed that fresh organic matter increased plant concentrations of Ca and Mg but mature compost did not. Reports in the literature suggest that response to Ca and Mg in organic wastes may be crop specific. For example, Wen *et al.* (1999) found that although organic wastes affected the concentration of Ca and Mg in lettuce, this was not the case in bean pods. As expected, crop response varies with waste type. Wen *et al.* (1999) observed that Ca and Mg concentrations increased with sludge application but decreased with composted manure.

<u>3.4.3. Product quality</u>

There are surprisingly few reports of the effect of composts on product quality, using quality in a wider sense than just nutrient content. There is some information on the effects of slurry and manures on quality. For example, Jackson and Smith (1997) found that spring applied slurry was more efficient for grain protein than autumn applied slurry. It can be anticipated that the same nutritional controls of quality will apply whether the source of nutrients is mineral or organic. For example, grain quality can suffer from both an under supply and an over supply of N. However, the ability of organic materials to supply a balance of mineral elements could potentially improve product quality. There is also appears to be little information available on the effects of composts on differential development of crop maturity or above and belowground crop development. Humic acids extracted from sewage sludge and compost have however been shown to favour the development of the aboveground growth of barley (Ayuso *et al*., 1996).

3.4.4. Plant health (See Objective 4)

3.5 Tools and models for compost application

Improving soil fertility in organic farming through the use of composts relies on improved understanding of the effects of feedstocks, composting and application methods on soil fertility and also on improved technology transfer of research results into practice. This requires the provision of good on-farm advice by advisors who fully understand the complexity of managing soil fertility in organic farming systems. The development and widespread accessibility of appropriate tools to support decision-making is central to this (Wander and Drinkwater, 2000). Rangarajan *et al.* (2002) working with New York fruit and vegetable growers highlighted the need for farmer training not only in relation to manure and water quality but also in relation to food safety and the use of composting to kill pathogens.

Farmers often underestimate the nutrient values of organic materials (Smith and Chambers, 1993) and thus analyses of materials prior to application are a constructive educational tool (Sharpley and Rekolainen, 1997). Use of both soil and organic material analyses can help to plan crop production and minimise adverse environmental impacts.

It is a challenge to develop user-friendly tools that can predict nutrient transformations from added organic materials to meet crop demand and avoid N losses by leaching and volatilization and P losses by run-off. A large number of models of nutrient cycling in agricultural systems have been developed, many are complex mathematical models with substantial data input requirements which reduce their practical use. Sommer and Hutchings (2001) reviewed five empirical models and concluded that none of them were suitable for giving day-to day advice to farmers. The MANNER model (Chambers *et al*., 1999) estimates the amount of N available to crops following the application of livestock manures after calculating losses by leaching and volatilization. The model has been used to test the trade-off effects of changing practices to reduce ammonia loss on leaching and nitrous oxide losses (Webb *et al*., 2001). A development of MANNER called MANMOD for organic farming systems is currently being funded by DEFRA. Other models like SUNDIAL (Smith *et al*., 1996) and WELL-N (Rahn *et al*., 2001) which models nutrient flows were initially designed for fertilizer based systems and require further development to model N flows in systems with a heavy reliance on legumes, manures and composts. Gerke *et al.* (1999) used the Danish DAISY model to model the long-term effects of compost application nitrate leaching and crop production. They showed that compost maturity was less important than site differences and management practices such as rotation. They stress that this analysis should not be used as a management tool and only as an indicator of relative differences between possible scenarios.

3.6 Systems aspects

In making recommendations for compost use in organic agriculture, the rotational aspects of the system need to be taken into account. For example, it is important to take into account factors such as the depression of nitrogen fixation caused by N application. This is also important in the design of future research. HDRA (2001) were unable to assess clearly the effects of composts on crop yields within an organic farm because the compost had been used in addition to the normal fertility building practices on the farm (including legumes and animal manure applications).

On organic farms, where the importation of materials to build/maintain soil fertility is restricted, it is important that a balance between inputs and outputs of nutrients is achieved to ensure both short-term productivity and long-term sustainability. Nutrient management must be understood, planned and managed over periods of longer than a single crop or growing season (Watson *et al.*, 2002b). There is thus a need to determine on which crops, and in what stages of the rotation, compost is most beneficial. Ott (1996) developed a strategy for manure handling on organic farms, where manure management is directed towards soil conditions and specific crop husbandry. Table 3b summarises the ideas proposed by Ott (1996). This idea could be further developed for specific nutrients, for example, the use of low N composts to add P and K to low N demanding crops, and high N composts on crops with a high N demand. Herbage composts based on grass have been shown to have very high K contents (Eklind *et al*., 1998) that may be useful on sandy soils or in stockless organic horticultural systems. However, where composts contain high P and K levels, application rates should be determined on the basis of P and K rather than N requirements (Reider *et al*., 2000). From a review of nutrient budgets on organic farms, Watson *et al.* (2002b) concluded that balancing P and K offtake in organic produce with P and K inputs from organically acceptable sources was a priority in organic systems. Similarly, farms will export trace elements in crop and livestock products and there will be a need to balance outputs with inputs in order to maintain the nutrient resource capital of the farm (Owens and Watson, 2002). Nutrient budgets may be one way of highlighting nutrient imbalances, and helping to plan the use of composted materials to redress the balance.

Table 4b Guidelines for the application of stockpiled and composted manure on organic farms (adapted from Ott, 1996)

Criteria	**Composted FYM**	**Stacked FYM**
Aim of fertilization	Soil organic matter	Nutrient application
Soil type	Sandy	Clay
Crop rotation	High proportion of legumes	Low proportion of legumes
Crop specific needs:		
Time to maturity	Long	Short
Nutrient demand	Low	High
Nitrate accumulation	Yes	No

3.7 Conclusions

3.7.1 General conclusions

- Caution must be exercised in generalising on the effects of composts on manures on soil health, fertility and crop nutrition due both to the variable nature of composts, and their interactions with climatic, edaphic and crop properties.
- While the general effects of the use of composts and manures on soil physical and chemical properties are well understood, the interactions between composts and manures, soil properties, tillage and rotation are less well characterised.
- While general principles are likely to be applicable in both conventional and organic systems, caution must be exercised in drawing comparisons between use of composts and manures in organic and conventional farming. This is due to the different composition of manures from organic farms and the restrictions of the organic standards but also due to the different rotations and cropping patterns which exist in the two systems.
- There is a need to address manure and compost applications in the context of farming systems rather than individual crops.

3.7.1 Specific conclusions

- Manures and composts tend to increase soil organic matter content, reduce bulk density and increase porosity.
- Manures and composts generally improve aggregate stability
- Compost can have a significant impact on stabilising vulnerable soils against erosion
- As a result of increasing the soil organic matter content, composts and manures. generally increase cation exchange capacity.
- Composts and manures can have a significant affect on soil pH.
- Composts are generally of little value as N fertilizers compared with fresh manures.
- N availability from composts and manures is dependent on C/N ratio. High C/N ratio materials can immobilise N. C/N ratio can potentially be used to manipulate N supply in the field.
- Application of composts at rates that are likely to produce a significant N response will generally oversupply P and K.
- P availability is generally similar from raw and composted materials, responses are usually proportional to total P applied.
- Compost is often a poor source of K due to leaching loss during composting.
- Composting of organic wastes does not appear to affect K availability.
- Gaseous nitrogen losses tend to be lower from composted than fresh organic materials, but management options to minimise these losses need further development.
- There is a need to investigate trade-off's between different gaseous and leaching forms of pollutants following compost application. This should include methane and carbon dioxide.
- There is little information on pathogen persistence and movement in soils/water following spreading.
- Gaseous and leaching losses from the use of compost need to be assessed in the context of the farming system rather than for individual crops.
- Manures and composts have the potential to improve and crop nutrition. They may be particularly beneficial in terms of minor elements.
- There is very little information available on the effects of compost on product quality in field grown crops.
- There is a need to adapt models of nutrient cycling and loss for use in organic systems.

References

Aggelides, S.M. and Londra, P.A. (2000) Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil. *Bioresource Technology* 71, 253-259.

Albiach, R., Canet, R., Pomares, F. and Ingelmo, F. (2001) Organic matter components and aggregate stability after the application of different amendments to a horticultural soil. *Bioresource Technology* 76, 125-129.

Arnesen, A.K.M. and Singh, B.R. (1998) Plant uptake and DTPA-extractability of Cd, Cu, Ni and Zn in a Norwegian alum shale soil as affected by previous addition of dairy and pig manures and peat. *Canadian Journal of Soil Science* 78, 531-539.

Atkinson, D. and Watson, C.A. (2000) The research needs of organic agriculture – distinct or just part of agricultural research? The BCPC Conference - Pests & Diseases 2000, 151-158.

Avery DT (1998) The hidden dangers of organic food. American Outlook 1998, Fall, 19-22.

Ayuso, M., Hernández, T., Garcia, C. and Pascual, J.A. (1996) Stimulation of barley growth and nutrient absorption by humic substances originating from various organic materials. *Bioresource Technology* 57, 251-257.

Barker, A.V. 1997 Composition and use of composts. In JE Rechcigl & HC MacKinnon (eds.) *Agricultural use of by-products and wastes.* ACS Symposium Series 668. ACS, Washington DC, USA, pp 140-162.

Båth, B. and Rämert, B. (2000) Organic household wastes as a nitrogen production source in leek production. Acta Agriculturæ Scandinavica 49, 201-208.

Baziramakenga, R., Simard, R.R. and Lalande, R. (2001) Effect of de-inking paper sludge compost application on soil chemical and biological properties. *Canadian Journal of Soil Science* 81, 561-575.

Bazoffi, P., Pellegrini, F., Rocchini, A., Morandi, M. and Grasselli, O. (1998) The effect of urban waste compost and different tractor tyres on soil physical properties. *Soil and Tillage Research* 44, 275-286.

Bevacqua, R.F. and Mellano, V.J. (1994) Cumulative effects of sludge compost on crop yield and soil properties. *Communications in Soil Science and Plant Analysis* 24, 395-406.

Bohn, H., McNeal, B. and O'Connor, G. (1979) *Soil Chemistry*. John Wiley and Sons, New York, USA.

Bresson, L.M., Koch, C., Le Bissonnias, Y., Barriuso, E. and Lecomte, V. (2001) Soil surface stabilization by municipal waste compost application. *Soil Science Society of America Journal* 65, 1804-1811.

Brinson, S.E., Cabrera, M.L. and Tyson, S.C. (1994) Ammonia volatilization from surface-applied, fresh and composted poultry manure. *Plant and Soil* 167, 213-218.

Canarutto, S, Pera, A., La Marca, M. and Vallini, G. (1996). Effects of humic acids from compost-stabilized green waste or Leonardite on soil shrinkage and microaggregation. *Compost Science and Utilization* 4, 40-46.

Chambers, B.J., Lord, E.I., Nicholson, F.A. and Smith, K.A. (1999) Predicting nitrogen availabiliity and losses following arable land application of manures: MANNER. *Soil Use and Management* 16, 157-161.

Chang, A.C., Page, A.L. and Warneke, J.E. (1983) Soil conditioning effect of municipal sludge compost. *Journal of Environmental Engineering* 109, 574-583.

Chang, C., Cho, C.M. and Janzen, H.H. (1998) Nitrous oxide emissions from long-term manured soils. *Soil Science Society of America Journal* 62, 677-682.

Chang, C., Sommerfeldt, T.G. and Entz, T. (1991) Soil chemistry after eleven annual applications of cattle feedlot manure. *Journal of Environmental Quality* 20, 475-480.

Chapman, A., Siddons, C.A., Cerdan Malo, A.T. and Harkin, M.A. (1997) A 1 year study of *Escherichia coli* O157 in cattle, sheep, pigs and poultry. *Epidemiology and Infection* 119, 245-250.

Chen, L., Dick, W.A., Streeter, J.G, and Hoitink, H.A.J. (1996) Ryegrass utilization of nutrient released from composted biosolids and cow manure. *Compost Science and Utilization* 4, 73-83.

Cooperband, L., Bollero, G and Coale, F. (2002) Effect of poultry litter and composts on soil nitorgen and phosphorus availability and corn production. *Nutrient Cycling in Agroecosystems* 62, 185-194.

Cormack, W F. (1997). Testing the sustainability of a stockless arable rotation on a fertile soil in Eastern England. In: J Isart and JJ Llerena (eds.) *Resource Use in Organic Farming*, ENOF, Barcelona, pp. 127-135.

Crecchio, C., Curci, M., Mininni, R., Riccuti, P. and Ruggiero, P. (2001) Short-term effects of municipal solid waste compost amendments on soil carbon and nitrogen content, some enzyme activities and genetic diversity. *Biology and Fertility of Soils* 34, 311-318.

Debosz, K., Petersen, S.O. Kure, L.K. and Ambus, P. (2001) Evaluating effects of sewage sludge and household compost on soil physical, chemical and microbiological properties. *Applied Soil Ecology* 19, 237-248.

Dewes, T. and Hünsche, E. (1998) Composition and microbial degradability in the soil of farmyard manure from ecologically-managed farms. *Biological Agriculture and Horticulture* 16, 261-268.

De Wever, H., Mussen, S. and Merckx, R. (2002) Dynamics of trace gas production following compost and NO_3^- amendments to soil at different initial TOC/ NO_3^- ratios. *Soil Biology and Biochemistry* 34, 1583-1591.

Di, H.J. and Cameron, K.C. (2002) Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. *Nutrient Cycling in Agroecosystems* 46, 237-256.

ECETOC (1994) *Ammonia emissions to air in Western Europe*, Technical Report No 62. European Centre for Ecotoxicology and Toxicology of Chemicals. Brussels, Belgium.

Eghball, B. (2002) Soil properties as influenced by phosphorus- and nitrogen-based manure and compost applications. *Agronomy Journal* 94, 128-135.

Eghball, B. and Power, J.F. (1999) Phosphorus- and nitrogen-based manure and compost applications: corn production and soil phosphorus. *Soil Science Society of America Journal* 63, 895-901.

Edwards, L., Burney, J.R., Rochter, G. & MacRae, A.H. (2000) Evaluation of compost and straw mulching on soil-loss characteristics in erosion plots of potatoes in Prince Edward Island, Canada. *Agriculture, Ecosystems and Environment* 81, 217-222.

Egelkraut, T.M., Kissel, D.E. and Cabrera, M.L. (2000) Effect of soil texture on nitrogen mineralized from cotton residues and compost. *Journal of Environmental Quality* 29, 1518-1522.

Ekbladh, G. (1995) Nitrogen effects on leeks. Influence of raised beds and mulching on nitrogen availability. *Biological Agriculture and Horticulture* 11, 151-171.

Eklind, Y., Salomonsson, L., Wivstad, M. and Rämert, B. (1998) Use of herbage compost as horticultural substrate and source of plant nutrients. *Biological Agriculture and Horticulture* 16, 269-290.

Epstein, E. (1997) *The science of composting*. Technomic Publishing Company Incorporated, Lancaster, PA, USA.

Eriksen, G.N., Coale, F.J. and Bollero, G.A. (1999) Soil nitrogen dynamics and maize production in municipal solid waste amended soil. *Agronomy Journal* 91, 1009-1016.

Fauci, M.F., Bezdicek, D.F., Caldwell, D. and Finch, R. (1999) End product quality and agronomic performance of compost. *Compost Science and Utilization* 7, 17-29.

Gagnon, B. and Simard, R.R. (1999) Nitrogen and phosphorus release from on-farm and industrial composts. *Canadian Journal of Soil Science* 79, 481-489.

Gagnon, B., Lalande, R. and Fahmy, S.H. (2001) Organic matter and aggregation in a degraded potato soil as affectd by raw and composted pulp residue. *Biology and Fertility of Soils* 34, 441-447.

Garcia, C., Hernandez, T. and Costa, F. (1991) The influence of composting on the fertilizer value of an aerobic sewage sludge. *Plant and Soil* 136, 269-272.

Gerke, H.H., Arning, M. and Stöppler-Zimmer, H. (1999) Modeling long-term compost application effects on nitrate leaching. *Plant and Soil* 213, 75-92.

Giusquiani, P.L., Pagliai, M., Giglotti, G., Buisinelli, D. and Beneti, A. (1995) Urban waste compost: Effects on physical, chemical and biochemical soil properties. *Journal of Environmental Quality* 24, 175-182.

Gooding, M.J., Cosser, N.D., Thompson, A.J., Davies, W.P. and Froud-Williams, R.J. (1997). The effect of cultivar and *Rht* genes of the competitive ability, yield and breadmaking quality and of organically grown winter wheat. In: J Isart and JJ Llerena (eds.) *Resource Use in Organic Farming*, ENOF, Barcelona, pp 113-126.

Gove, L., Nicholson, F.A., Cook, H.F. and Beck, A.J. (2002) Comparison of the effect of surface application and subsurface incorporation of enhanced treated biosolids on the leaching of heavy metals and nutrients through sand and sandy loam soils. *Environmental Technology* 23, 189-198

Graham, R.D. and Webb, M.J. (1991) Micronutrients and resistance and tolerance to disease In: J.J. Mortvedt, F.R. Cox, L.M. Shuman and R.M. Welch (eds.) *Micronutrients in Agriculture*, 2nd edition, Soil Science Society of America, Madison, Wisconsin, USA, pp 329-370.

Guidi, G., Pera,A., Giovanetti, M., Poggio, G. and Bertoldi, M. (1988) Variation in soils structure and microbial population in a compost amended soil. *Plant and Soil* 106, 113-119.

Gunapala,N. and Scow,K.M. (1998) Dynamics of soil microbial biomass and activity in conventional and organic farming systems. *Soil Biology and Biochemistry* 30, 805-816.

Hadas, A. and Portnoy, R. (1997) Rates of decomposition in soil and release of available nitrogen from cattle manure and municipal waste composts. *Compost Science and Utilization* 5, 48-54.

Handayanto, E., Cadish, G. and Giller, K.E. (1997) Regulating N mineralisation from plant residues by manipulation of quality. In: G. Cadish and K.E. Giller (eds.) *Driven By Nature: Plant Litter Quality and Decomposition*, CAB International, Wallingford, UK, pp175-185.

Haynes, R.J. and Naidu, R. (1998) Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutrient Cycling in Agroecosystems 51,123-137.

HDRA (2001) Researching the use of compost in agriculture. Report of field trials 1997-2000.

Hernando, S., Lobo, M.C., and Polo, A. (1989) Effect of the application of municipal refuse compost on the physical and chemical properties of a soil. *The Science of the Total Environment* 81/82 589-596.

Hue, N.V. (1992) Correcting soil acidity of a highly weathered Ultisol with chicken manure and sewage sludge. *Communications in Soil Science and Plant Analysis* 23, 241-264.

Hue, N.V. (1988) Residual effect of sewage-sludge application on plant and soil-profile chemical composition. *Communications in Soil Science and Plant Analysis* 19, 1633-1643.

Jackson, D.R. and Smith, K.A. (1997) Animal manure slurries as a source of nitrogen for cereals; effect of application time on efficiency. *Soil Use and Management* 13, 75-81.

Jakobsen, S.T. (1996) Leaching of nutrients from pots with and without applied compost. *Resources, Conservation and Recycling* 17, 1-11.

Jarvis, S.C., Stockdale, E.A., Shepherd, M.A. and Powlson, D.S. (1996) Nitrogen mineralization in temperate agricultural soils: processes and measurement. *Advances in Agronomy* 57, 187-235.

Johnston, A.E. (1986) Soil organic matter effects on soils and crops. *Soil Use and Management* 2, 97-105.

Johnston, A.E., McGrath, S.P., Poulton, P.R. and Lane, P.W. (1989) Accumulation and loss of nitrogen from manure, sludge and compost: long-term experiments at Rothamsted and Woburn. In: J.A. Hansen and K. Henriksen (eds.) *Nitrogen in organic wastes applied to soils.* Academic Press, London, UK, pp 126-137.

Jones, P.W. (1982) Waste and animal health. *Public Health Engineering* 10, 35-39.

Kaiser, E-A., Kohrs, K., Kücke, M., Scnug, E., Heinemeyer, O. and Munch, J.C. (1998) Nitrous oxide release from arable soil: importance of N fertilization, crops and temporal variation. *Soil Biology and Biochemistry* 30, 1553-1563.

Kearney, T.E., Larkin, M.J., Frost, J.P. and Levett, P.N. (1993) Survival of pathogenic bacteria during mesophilic anaerobic digestion of animal waste. *Journal of Applied Bacteriology* 74, 86-93.

Kirchmann, H. (1985) Losses, plant uptake and utilisation of manure nitrogen during a production cycle. Acta Agriculturæ Scandinavica Supplementum 24, 1-77.

Kirchmann, H. (1989) A 3 year N-balance study with aerobic, anaerobic and fresh 15N-labelled poultry manure. In: J.A. Hansen and K. Henriksen (eds.) *Nitrogen in organic wastes applied to soils.* Academic Press, London, UK, pp 113-125.

Klausner, S.D., Kanneganti, V.R. and Bouldin, D.R. (1994) An approach for estimating a decay series for organic nitrogen in animal manure. *Agronomy Journal* 86, 897-903.

Lampkin, N and Measures, M. (2001) *The Organic Farm Management Handbook* 4th Edition, Organic Framing Research Unit, Aberystwyth.

Leclerc, B., Georges, P., Beatrice, C. and Lairon, D. (1995) A five year study on nitrate leaching under crops fertilised with mineral and organic fertilisers in lysimeters. In: L. Kristensen, C. Stopes, P. Kølster, A. Granstedt and D. Hodges (eds.) *Nitrate Leaching in Ecological Agriculture*. AB Academic Publishers, Bicester, Uk, pp 301-308.

Lobo, M.C. (1988) The effect of compost from vine shoots on the growth of barley. *Biological Wastes* 25, 281-290.

Lung, A.J., Lin, C.M., Kim, J.M., Marshall, M.R., Norstedt, R., Thompson, N.P. and Wei, C.I. (2001) Destruction of Escherichia coli O157:H7 and Salomonella Enteritidis in cow manure composting. *Journal of Food Protection* 64, 1309-1314.

MacLeod, J.A., Sanderson, J.B. and Douglas, B. (2000) Nutrient content of barley and red clover as influenced by application of compost. *Communications in Soil Science and Plant Analysis* 31, 2439-2444.

Manna, M.C., Ghosh, P.K., Ghosh, B.N. and Singh, K.N. (2001) Comparative effect of phosphate-enrcihed compost and single superphosphate on yield, uptake of nutrients and soil quality under soybean-wheat rotation. *Journal of Agricultural Science, Cambridge* 137, 45-54.

Marchesini, A., Allievi, L., Comotti, E. and Ferrari, A. (1988) Long-term effects of quality-compost treatment on soil. *Plant and Soil* 106, 253-261.

Mawdsley, J.L., Bardgett, R.D., Merry, R.J., Pain, B.F. and Theodorou, M.K. 1995. Pathogens in livestock waste, their potential for movement through soil and environmental pollution. *Applied Soil Ecology* 2, 1-15.

McConnell, D.B., Shiralipour, A. and Smith,W.H. (1993) Compost Application Improves Soil Properties. *Biocycle* 34, 61-63.

McMurry, S.W., Coyne, M.S. and Perfect, E. (1998) Fecal coliform transport through intact soil blocks amended with poultry manure. *Journal of Environmental Quality* 27, 86-92.

Mogge, B., Kaiser, E-A and Munch, J.C. (1999) Nitrous oxide emissions and denitrifcation N-losses from agricultural soils in the Bornhöved Lake region: influence of organic fertilizers and land-use. *Soil Biology and Biochemistry* 31, 1245-1252.

Mokolabate, M.S. and Haynes, R.J. (2002) Comparative liming effect of four organic residues applied to an acid soil. *Biology and Fertility of Soils* 35, 79-85.

Moore, P.A. and Miller, D.M. (1994) Decreasing phosphorus solubility in poultry manure litter with aluminium, calcium and iron amendments. *Journal of Environmental Quality* 23, 325-330.

Movahedi Naeini, S.A.R. and Cook, H.F. (2000) Influence of municipal compost on temperature, water, nutrient status and the yield of maize in a temperate soil. *Soil Use and Management 16*, 215-221.

Nemati, M.R., Caron, J. and Gallichand, J. (2000) Stability of structural form during infiltration: laboratory measurements on the effects of de-inking sludge. *Soil Science Society of America Journal* 64, 543-552.

Ott, P. (1996) Utilization of manure and composted farmyard manure. “A manuring strategy” In: H. Vogtmann, E. Boehncke & I. Fricke (eds.) *The importance of biological agriculture in a world of diminishing resources.* Verlagsgruppe, Witzenhausen, pp, 310-316.

Owens, K. & Watson, C. (2002). Nutrient budgeting for trace elements: Examples from Scottish organic farms. *Proceedings of the UK Organic Research 2002 Conference*, 147-148.

Pagliai, M., Guidi, G., La Marca, M., Giachetti, M. and Lucamante, G. (1981) Effects of sewage sludge and composts on soil porosity and aggregation. *Journal of Environmental Quality* 4, 556-561.

Pain, B.F., Misselbrook, T.A. and Rees, Y.T. (1993) Effect of nitrification inhibitor and acid addition on nitrogen losses and herbage yield. *Grass and Forage Science* 49, 209-215.

Paré, T., Dinel, H., Moulin, A.P. and Townley-Smith, T. (1999) Organic matter quality and structural stability of a Black Chernozemic soil under different manure management practices. *Geoderma* 91, 311-326.

Poudel, D.D., Horwath, W.R., Lanini, W.T., Temple, S.R. and van Bruggen, A.H.C. (2002) Comparison of soil N availability and leaching potential, crop yields and weeds in organic, low-input and conventional systems in northern California. *Agriculture, Ecosystems and Environment* 90, 125-137.

Purves, D. and McKenzie, E.J. (1974) Phytotoxicity due to boron in municipal compost. *Plant and Soil* 40, 231-235.

Rahn, C., Mead, A. Draycott, A., Lillywhite, R. and Salo, T. (2001) A sensitivity analysis of the nitrogen fertilizer requirement of cauliflower using the HRI WELL_N computer model. *Journal Of Agricultural Science, Cambridge* 137, 55-69.

Rahn, C.R., Vaidyanthan, L.V. and Paterson, C.D. (1992) Nitrogen residues from brassica crops. *Aspects of Applied Biology* 30, 263-270.

Rangarajan, A., Pritts, M.P., Reiners, S. and Pedersen, L.H. (2002) Focusing food safety training based on current grower practices and farm scale. *Horttechnology* 12, 126-131.

Reganold, J.P., Glover, J.D., Andrews, P.K. and Hinman, H.R. (2001) Sustainability of three apple production systems. *Nature* 410, 926-929.

Reider, C.R., Herdman, W.R., Drinkwater, L.E. and Janke, R. (2000) Yields and nutrient budgets under composts, raw dairy manure and mineral fertilizer. *Compost Science and Utilization* 8, 328-339.

Ros, M., Garcia, C. and Hernandez, T. (2001) the use of urban organic wastes in the control of erosion in a semiarid Mediterranean soil. *Soil Use and Management* 17, 292-293.

SAC (2002) *The SAC Farm Management Handbook 2002/3*, SAC Edinburgh.

Sanchez, J.E., Willson, T.C., Kizilkaya, K., Parker, E. and Harwood, R.R. (2001) Enhancing the mineralizable nitrogen pool through substrate diversity in long term cropping systems. *Soil Science Society of America Journal* 65, 1442-1447.

Scott, A., Ball, B.C., Crichton, I.J. and Aitken, M.A. (2000) Nitrous oxide and carbon dioxide emissions from grassland amended with sewage sludge. *Soil Use and Management* 16, 36-41.

Sharpley, A. and Moyer, B. (2000) Phosphorus forms in manure and compost and their release during simulated rainfall. *Journal of Environmental Quality* 29, 1462-1469.

Sharpley, A.N. and Rekolainen, S. (1997) Phosphorus in agriculture and its environmental implications. In: H. Tunney, O.T. Caton, P.C. Brookes and A.E. Johnston (eds.) *Phosphorus loss from soil to water.* CAB International, Wallingford, UK, pp 1-53.

Shepherd, M.A., Bhogal, A., Lennartsson, M, Rayns, F., Jackson, L., Philipps, L. and Pain, B. (1999) The environmental impact of manure use in organic farming. Final Report to MAFF.

Shiralipour, A., McConnell, D.B. and Smith, W.H. (1992) Physical and chemical properties of soils as affected by municipal solid waste compost application. *Biomass and Bioenergy* 3, 261-266.

Simard, R.R., Baziramakenga, R., Yelle, S. and Coulombe, J. (1998) Effects of de-inking paper sludges on soil properties and crop yields. *Canadian Journal of Soil Science* 78, 689-697.

Smith, K.A., Chalmers, A.G., Chambers, B.J. and Christie, P. (1998) Organic manure phosphorus accumulation, mobility and management. *Soil Use and Management* 14, 154-159.

Smith, K.A. and Chambers, B.J. (1993) Utilising the nitrogen content of organic manures on farms – problems and practical solutions. *Soil Use and Management* 9, 105-112.

Smith, J.U., Bradbury, N.J. and Addiscott, T.M. (1996) SUNDIAL: A PC-based system for simulating nitrogen dynamics in arable land. *Agronomy Journal* 88, 38-43.

Soil Association (2000) *Organic farming, food quality and health. A review of the evidence.* Soil Association, Bristol.

Sommer, S.G. and Hutchings, N.J. (2001) Ammonia emissions from field applied manure and its reduction – invited paper. *European Journal of Agronomy* 15, 1-15.

Sommer, S.G. and Olesen, J.E. (1991) Effects of dry matter content and temperature on ammonia loss from surface applied cattle slurry. *Journal of Environmental Quality* 23, 493-498.

Sorber, C.A. and Moore, B.E. (1986) Survival and transport of pathogens in sludge amended soils. In: *Proceedings of the National Conference on Municipal Treatment Plant Sludge Management*. Orlando FL, USA.

Stamatiadis, S., Werner, M. and Buchanan, M. (1999) field assessment of soil quality as affected by compost and fertilizer application in a broccoli field (San Benito County, California). *Applied Soil Ecology* 12, 217-225.

Starling, W. and Richards, M.C. (1993) Quality of commercial samples of organically-grown wheat. *Aspects of Applied Biology* 36, 205-209.

Stephenson, J. (1997) Public health experts take aim at a moving target: foodborne infections. *Journal American Medical Association* 27, 97-98.

Stockdale, E.A., Lampkin, N.H., Hovi, M., Keatinge, R., Lennartsson, E.K.M., MacDonald, D.W., Padel, S., Tattersall, F.H., Wolfe, M.S., Watson, C.A. (2001) Agronomic and environmental implications of organic farming systems. *Advances in Agronomy* 70, 261-327.

Stockdale, E.A,. McKinlay, R.G. and Rees, R.M. (1992) Soil nitrogen management and interactions with pests and diseases in organic farming. *Aspects of Applied Biology* 30, 387-392.

Stockdale, E.A. and Rees, R.M. (1995) Release of nitrogen from plant and animal residues and consequent plant uptake efficiency. *Biological Agriculture and Horticulture* 11, 229-245.

Swift, M.J. and Palm, C.A. (2000) Soil fertility as an ecosystem concept: A paradigm lost or regained? In: *Accomplishments and changing paradigm towards the 21st Century*.

Sylvester-Bradley, R. (1993) Scope for more efficient use of fertilizer nitrogen. *Soil Use and Management* 9, 112-117.

Tisdall, J.M. and Oades, J.M. (1980) The effect of crop rotation on aggregation in a red-brown earth. *Australian Journal of Soil Research* 18, 423-434.

Tyson, S.C. and Cabrera, M.L. (1993) Nitrogen mineralisation in soils amended with composted and uncomposted poultry manure. *Communications in Soil Science and Plant Analysis* 24, 2361-2374.

UKROFS (2001) United Kingdom register of organic food standards. Reference OB4, London, UKROFS.

Vagstad, N., Broch-Due, A. and Lyngstad, I. (2001) Direct and residual effects of pulp and paper mill sludge on crop yield and soil mineral N. *Soil Use and Management 17*, 173-178.

Vanlauwe, B., Diels, J., Sanginga, N. and Merckx, R. (1997) Residue quality and decomposition: An unsteady relationship? In: G. Cadish and K.E. Giller (eds.) *Driven By Nature: Plant Litter Quality and Decomposition*, CAB International, Wallingford, UK, pp157-166.

Vinten, A.J., Davis, R., Castle, K. and Baggs, E.M. (1998) Control of nitrate leaching from a nitrate vulnerable zone using paper mill waste. *Soil Use and Management 14*, 215-222.

Vinten, A.J., Lewis, D.R., Fenlon, D.R., Leach, K.A., Howard, R., Svoboda, I. and Ogden, I. (2002) Fate of *Escherichia coli and Escherichia coli* O157 in soils and drainage water following cattle slurry application at 3 sites in Southern Scotland. *Soil Use and Management* 18, 223-231.

Vitosh, M.L., Davids, J.F. and Knezek, B.D. (1973) Long-term effects of manure, fertilizer, and plow depth on chemical properties of soil and nutrient movement in a monoculture corn system. *Journal of Environmental Quality* 2, 296-299.

Wander, M.M. and Drinkwater, L.E. (2000) Fostering soil stewardship through soil quality assessment. *Applied Soil Ecology* 15, 61-73.

Warman, P.R. and Cooper, J.M. (2000a) Fertilization of a mixed forage crop with fresh and composted chicken manure and NPK fertiliser: Effects on dry matter yield and soila nd tissue N, P and K. *Canadian Journal of Soil Science* 80, 337-344.

Warman, P.R. and Cooper, J.M. (2000b) Fertilization of a mixed forage crop with fresh and composted chicken manure and NPK fertiliser: Effects on soil and tissue Ca, Mg, S, B, Cu, Fe, Mn and Zn. *Canadian Journal of Soil Science* 80, 345-352.

Watson, C.A., Atkinson, D., Gosling, P., Jackson, L.R. and Rayns, F.W. (2002a). Managing soil fertility in organic farming systems. *Soil Use & Management* 18, 239-247.

Watson, C. A., Bengtsson, H., Løes, A-K., Myrbeck, A., Salomon, E., Schroder, J. & Stockdale, E.A. (2002b). A review of farm-scale nutrient budgets for organic farms as a tool for management of soil fertility. *Soil Use and Management* 18, 264-273.

Webb, J., Henderson, D. and Anthony, S.G. (2001) Optimizing livestock manure applications to reduce nitrate and ammonia pollution: scenario analysis using the MANNER model. *Soil Use and Management* 17, 188-194.

Van Assche, C. and Uyttebroecke, P. (1982) Demand supply and application possibilities of domestic waste compost in agriculture and horticulture. *Agricultural Wastes* 4, 203-212.

Vervoort, R.W., Radcliffe, D.E., Cabrera, M.L. and Latimore, M. (1998) Nutrient losses in surface and subsurface flow from pasture applied poultry litter and composted poultry litter. *Nutrient Cycling in Agroecosystems* 50, 287-289.

Wen, G., Bates, T.E., Voroney, R.P., Winter, J.P. and Schellenberg, M.P. (1999) Influence of application of sewage sludges, and sludge and manure composts on plant Ca and Mg concentration and soil extractability in field experiments. *Nutrient Cycling in Agroecosystems* 55, 51-61.

Wen, G., Winter, J.P., Voroney, R.P. and Bates, T.E. (1997) Potassium availability with application of sewage sludge and sludge and manure composts in field experiments. *Nutrient Cycling in Agroecosystems* 47, 233-241.

Wild, A. (1993) Soils and the Environment. An Introduction. Cambridge University Press, Cambridge, UK.

Whalen, J.K., Chang, C., Clayton, G.W. and Carefoot, J.P. (2000) Cattle manure amendments can increase the pH of acid soils. *Soil Science Society of America Journal* 64, 962-966.

Woodbury, P.B. (1992) Trace elements in municipal soil waste composts: A review of potential detrimental effects on plants, soil biota and water quality. *Biomass and Bioenergy* 3, 239-259.

Yan, W., Yamamoto, K. and Yakushido, K. (2002) Changes in nitrate content in different soil layers after the application of livestock waste compost pellets in a sweet corn field. *Soil Science and Plant Nutrition* 48, 165-170.

Zebarth, B.J., Neilsen, G.H., Hogue, E, and Neilsen, D. (1999) Influence of organic waste amendments on selected soil physical and chemical properties. *Canadian Journal of Soil Science* 79, 501-504.