Objective 4

A review of the effects of uncomposted materials, composts, manures and compost extracts on beneficial microorganisms, pest and disease incidence and severity in agricultural and horticultural crops.

Contents

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4.1 Introduction

4.1.1 Organic farming

The UK organic food and farming industry has undergone significant expansion during the past 15 years. Total UK retail sales have risen from £105M in 1993/94 to around £920M in 2001/02. This represents almost a nine-fold increase during that time. The area of UK land that is farmed organically has also grown rapidly and now makes up around 4.3 % of UK agricultural land (figures include in-conversion land and fully organic land in April 2002; Soil Association, 2002). In the UK, approximately 729,550 ha are currently registered as organic or in conversion, with 80.5% of that in rough grazing and permanent pasture, 12% in temporary ley, 0.3% in woodland, 5.8% in arable production and 1.4% used for horticultural crops (Soil Association, 2002).

Organic farming aims to enhance the natural biological cycles in soils, crops and livestock, by building up soil fertility through the use of nitrogen (N) fixation by legumes, by enhancing soil organic matter; and by avoiding pollution. The aim is to work with natural processes rather than seek to dominate them through the use of soluble fertilisers and pesticides. Use of non-renewable natural resources such as the fossil fuel used in the manufacture of fertilisers and pesticides is minimised. Organic farming principles also encompass high animal welfare standards and the improvement of the environmental infrastructure of the farm.

Legumes are the primary source of N on organic farms and are therefore, a fundamental component in organic farming systems. The supply of N and other nutrients to crops is maintained through enhanced nutrient cycling and microbial activity in the soil. This is achieved by various means including the use of grass/clover leys, use of crop types with varying root architecture and depth, application of organic manures and composts, shallow ploughing but deep aeration to maintain fertility in the surface layers and to avoid soil compaction, use of winter cover crops to minimise loss of soluble nutrients by leaching, etc.

Traditional organic farms produce a mixture of livestock and mainly arable crops. Animal feed is generally produced on the farm and the rotation is balanced to include a mix of fertility building and exploitative crops. Until the past 10 years, the limited amount of organic horticultural produce available came from small mixed intensive units where most operations (such as weeding and harvest) were carried out by hand. The recent expansion in organic farming has led to a diversification of farm types. The number of stockless farms, which rely on fertility building crops and imported bulky organic manures and composts for fertility, is increasing. The average size of the organic farm is increasing along with dependence on machinery for farm operations. The variety of crops grown is also increasing as the demand for novel organic vegetables, fibre crops and crops for processing grows. The change in the structure of organic farming is creating considerable challenges for organic producers and processors, particularly with regard to crop nutrition, soil management and pest and disease control (Litterick *et al.*, 2002; Watson *et al.*, 2002). There is an acute shortage of unbiased, science-based information to help farmers and growers optimise their production systems.

4.1.2 Uncomposted materials, composts, manures and compost extracts/teas

Composts and manures are of major importance in providing fertility in organic farming systems, since synthetic fertilisers are prohibited (Lampkin, 1990; Stockdale *et al.*, 2001. However, it has been known for some time that composts, manures, uncomposted plant materials and compost extracts or teas affect soils, crops and the organic farming system in several ways other than those relating simply to soil fertility. For example, the application of composts to soils has been shown to alter the balance of soil microflora and can suppress some soil-borne diseases in field crops (Hoitink and Fahy, 1986; Hoitink *et al*., 1997). The application of some types of crop residue has been shown to reduce numbers of plant pathogenic nematodes (Abawi and Widmer, 2000; Nicolay *et al*., 1990). The application of compost extracts or teas has also been shown to reduce the incidence and severity of foliar disease in some crops (Cronin *et al*., 1996; Scheuerell and Mahafee, 2002a; Weltzein, 1990).

Composts and manures are in increasingly short supply, particularly in the more modern, stockless systems and alternative feedstocks (to mixtures of animal excrement and bedding) which are permitted under the organic standards are being sought to address these shortages. Definitions of uncomposted materials, composts, manures and compost extracts/teas are given below.

4.1.2.1 Uncomposted materials

Uncomposted materials are defined in the context of this review as fresh plant residues including non-harvested plant parts such as cereal stubble, roots, leaves and rejected crop parts including root vegetables and fruits. The term uncomposted materials will not include any form of animal excrements in this review.

4.1.2.2 Composts and the composting process

Compost can be defined as solid particulate material that is the result of composting, that has been sanitized and stabilized and that confers beneficial effects when added to soil and/or used in conjunction with plants. Composting can be defined as a process of controlled biological decomposition of biodegradable materials under managed conditions that are predominantly aerobic and that allow the development of thermophilic temperatures as a result of biologically produced heat, in order to achieve compost that is sanitary and stable.

The principles of composting and the factors affecting the composting process are described in detail in section 2.3 of Objective 2.

4.1.2.3 Manures

Manures can be defined as animal excrement which may contain large amounts of bedding. It is important to distinguish between true composts (which contain material which has been composted) and stacked or stored manures which have not undergone aerobic composting.

4.1.2.4 Compost extracts and teas

The terms "compost extract" and "compost tea" have in the past been used interchangeably. However, for the purposes of this review, they are treated as different products.

Compost extracts are the filtered product of compost mixed with any solvent (usually water), but not fermented. This term has been used in the past to define water extracts prepared using a very wide range of different methods. In the past, the terms “compost extract”, “watery fermented compost extract”, “amended extract”, “compost steepage” and “compost slurry” have all been used to refer to non-aerated fermentations. "Compost extract", "watery fermented compost extract" and "steepages" are approximate synonyms defined as a 1:5 to 1:10 (v:v) ratio of compost to water that is fermented without stirring at room temperature for a defined length of time. "Amended extracts" are compost extracts that have been fermented with the addition of specific nutrients or microorganisms prior to application.

Compost teas are the product of showering recirculated water through a porous bag of compost suspended over an open tank with the intention of maintaining aerobic conditions. The product of this method has also been termed "aerated compost tea" and "organic tea".

In the past, the term "compost tea" has not always been associated with an aerated fermentation process. It is important to distinguish between compost teas prepared using aerated and non-aerated processes, therefore the terms aerated compost tea (ACT) and non-aerated compost tea (NCT) are used in this review to refer to the two dominant compost fermentation methods. ACT will refer to any method in which the water extract is actively aerated during the fermentation process. NCT will refer to methods where the water extract is not aerated or receives minimal aeration during fermentation apart from during the initial mixing.

4.1.2.5 Permitted inputs in organic farming systems

There are various rules relating to the type, quantity and source of bulky nutrient inputs which are allowed to be applied on organic farms. Manures and composts produced on organic farms are allowed to be spread on organic crop land providing the quantities applied do not exceed certain limits (170 kg N ha^{-1} yr^{-1}) in any one year. Manures from conventional or organic units other than the farm in question are allowed to be spread on organic farms, provided they do not come from intensive animal production systems. Organic farmers should always source their bulky fertilisers from their own farm, or another local organic farm in preference to a conventional farm.

Some regulations (e.g. Soil Association 2002/2003) state that manures from non-organic farms must be stacked or composted for defined periods of time prior to use. The application of composted or fermented household waste and vegetable matter are also permitted. Residues of genetically modified (GM) crops or composts containing feedstocks which contain GM crops, municipal solid waste/sewage sludge and catering wastes are all prohibited in organic systems. Further details on permitted, restricted and prohibited inputs in organic farming are provided in the standards produced by the certification bodies, for example, UKROFS standards (2001) and Soil Association standards for organic farming and production (2002/2003).

It is important to note that in relation to bulky nutrient inputs including composts and manures, there are two definitions of the word “organic” currently in use in the scientific literature. These include:

- The “agricultural” definition- as in organic farming pioneered by the Soil Association and now controlled by EU regulation.
- The “chemical” definition – meaning any chemical compounds containing carbon (C), including petrochemicals, plastics, all plants and animals and their by products.

4.1.3 Objectives of review

Composts, manures and uncomposted plant residues have widely different effects on the balance of soil microflora and plant pests and diseases depending on the nature of the residue concerned and its preparation method. Research suggests that composts and compost extracts/teas made from different feedstocks, or made using different techniques have widely different properties in relation to beneficial and pathogenic organisms (Aryantha *et al*., 2000; de Brito Alvarez *et al*., 1995; www.soilfoodweb.com).

The aim of this review is to assess the effects of uncomposted materials, composts, manures and compost extracts and teas on beneficial microorganisms, pest and disease incidence and severity in organic agricultural and horticultural crops.

4.2 Crop health and soil biology in organic agriculture and horticulture

4.2.1 Crop protection in organic systems

Organic crop protection strategies aim to prevent or minimise the development of pest, disease and weed problems through the provision of conditions which are optimal for crop growth and unsuitable for growth of pests, pathogens or weeds. Cultural practices including rotation design, choice of species and variety, sowing arrangements and intercropping are currently used to help prevent and control pests and diseases.

In practice, organic crop protection strategies normally combine direct (or reactive) and indirect (preventative or anticipatory) approaches. This applies in both conventional and organic farming, but given that in organic farming there are relatively few safety nets in terms of pesticides, the organic farmer must put most emphasis on preventative approaches. Integrated Crop Management (ICM) also features some of the approaches used in organic crop production, but there is greater reliance on preventative approaches in organic farming because of the restrictions on soluble fertiliser and pesticide use.

4.2.2 Pests and diseases in organic crops

An appropriate rotation is essential in order to reduce incidence and severity of pest and disease attack. Non-mobile pests which have a specific or narrow host range, such as nematodes, are particularly susceptible to crop rotation. Rotations may also aid the control of several insect pests such as cabbage stem weevil (*Ceutorhynchus quadridens*) and celery fly (*Euleia heraclei*) which have a limited host range and live in the soil for part of their life cycle. Highly mobile, often non-specific pests such as aphids are less affected or unaffected by rotation design. As with pests, the less mobile, soil-borne diseases such as rhizoctonia root rot and stem canker of potatoes (*Rhizoctonia solani*) and clubroot of brassicas (*Plasmodiophora brassicae*) are usually adequately controlled through the use of balanced rotations, appropriate break crops and good soil husbandry. It is often difficult to control root-inhabiting pathogens that survive saprophytically in soil organic matter and exist for long periods in the absence of a host plant. These pathogens include *Pythium* spp., some *Fusarium* and *Phytophthora* spp. and *Sclerotium rolfsii*.

The selection of varieties that have a high degree of resistance to locally significant pests and diseases is clearly an important element in organic crop protection strategy. This is especially important for diseases such as late blight in potatoes (*Phytophthora infestans*), which often have devastating effects. There is also increasing use of variety and species mixtures as an aid to foliar disease control and to improve yield stability. Mixtures may contain two or more varieties or species of similar crop type (e.g. cereals) which have different resistance patterns to common diseases. Such mixtures can significantly reduce disease levels and weed growth (Wolfe, 2002). Intercropping with two or more crop types (e.g. brassicas with an understorey of clover) has also been shown to reduce foliar disease and pest attack (Armstrong and McKinlay, 1997; Theunissen 1997).

Apart from the reduced disease pressure resulting from the more diverse cropping system, organic crops have a reduced N supply compared to conventional crops, and consequently a higher dry matter content and lower N content. This may make them less susceptible to air-borne or foliar disease. Cooke (1993) has shown that foliar and stem-base cereal disease levels are generally lower in long term organic fields than in recently converted fields. Soil borne pathogens and root disease are also generally lower in organic than in conventional systems (van Bruggen 1995).

With potentially serious foliar diseases such as potato blight, the effect can be reduced by enhancing the earliness of crop yield development, e.g. by chitting and choice of early, rather than late maturing varieties. Air-borne insect pests can be effectively controlled by using a physical barrier such as fleece, albeit at a considerable cost per hectare. It is also important to enhance populations of natural predators such as ladybirds and ground beetles by establishing beetle banks and/or boundary vegetation e.g. grass strips.

A number of naturally occurring fungicides and pesticides for direct control are permitted within the organic standards under specific circumstances. Sulfur, copper and some plant extract-based fungicides are permitted for control of foliar disease. Copper for control of blight in potatoes is probably the most commonly used of these in the UK. A maximum application rate of 8kg Cu per hectare per annum is permitted, reducing to 6kg per hectare per annum from 2006. Natural pesticides such as rotenone and quassia are permitted on a restricted basis under UKROFS regulations (UKROFS 2001). Biological control agents, originally developed for use in integrated horticultural systems, are permitted in some situations, for example *Bacillus thuringiensis* may be used to control lepidopterous pests in horticultural field crops. There are increasing numbers of new biological control products available in the UK and Europe which are claimed to stimulate the plant's own defences to disease, but in most cases there is little independent evidence of their efficacy in organic systems.

There is little or no application of uncomposted plant materials, composts, manures or compost extracts/teas specifically for the purpose of preventing or controlling pests or diseases in UK organic crops at present. However, conventional and organic farmers in the United States are reported to be applying disease suppressive composts and compost teas with some success (E. Ingham, pers. comm.; Scheuerell and Mahaffee, 2002a; www.attra.ncat.org).

4.2.3 Soil biology in organic farming systems

Soil organisms are central to soil and plant health and to the cycling of nutrients within the soil. Agricultural practices affect soil life directly and therefore also the patterns of nutrient cycling. The soil contains great numbers of organisms, many of which have important roles in nutrient cycling and protection of crops against pests and diseases. These can be classified into the following five groups:

- Microflora - bacteria, fungi, actinomycetes and microalgae
- Microfauna - organisms < 100 μm in size which feed on other micro-organisms, e.g. single celled protozoans, nematodes, rotifers etc.
- Mesofauna - larger organisms that feed on micro-organisms, decaying matter and living plants, e.g. mites, springtails and proturans
- Macrofauna - organisms generally larger than the mesofauna which feed on plants, other organisms or decaying matter, e.g. earthworms, slugs, snails, millipedes, beetles and their larvae
- Megafauna - the largest soil dwelling organisms including vertebrates such as voles and moles

Organic farming systems aim for efficient nutrient cycling through the maintenance of a large and diverse population of soil organisms. Nutrient cycling is largely driven by micro-organisms, but mesofauna and macrofauna (in particular earthworms) also play an important part in soil organic matter turnover. There have been numerous comparisons of the effects of conventional and organic/biodynamic farming systems on soil biological activity. Organic farming practices have generally been reported to have beneficial effects on earthworm populations (Pfiffner and Mader, 1997) and on soil microbial numbers, processes and activities (Shepherd *et al*., 2000). Experiments which showed no benefit of organic practices to microbial activity mainly relate to pasture systems, where the least difference between conventional and organic systems was seen, since both systems accumulate organic matter.

It is not possible to conclude that all organic farming systems have positive effects and conventional systems negative effects on numbers, processes and activities of soil fauna and microflora. The nature and magnitude of the response of individual organisms depends on soil type and climate and crop/soil/animal management practices as well as on the type of farming system.

There has been much interest recently in the idea of "functional redundancy" in the micro-organism populations present in soil (Shepherd *et al*., 2000). The hypothesis is that the number of species of soil organisms required for adequate functioning of soil processes is well below that which occurs naturally in most soils. It is known that there are certain "key" species such as N_2 -fixing organisms (Wardle and Giller, 1996) which must be present in order to ensure optimal nutrient cycling. The significance of species richness amongst non-key species is unclear, but it may be that diverse populations are more resilient in the face of environmental stresses (Kahindhi *et al*., 1997). Since organic farming systems do not allow synthetic fertiliser inputs and are totally reliant on efficient nutrient cycling for crop nutrient supply, the maintenance of diverse populations of soil organisms may help optimise nutrient cycling in the event of stresses due to unsuitable weather or soil conditions.

An additional advantage of maintaining soil biodiversity is the potential for protection against plant pests and pathogens. Some species of soil fauna and microflora are known to help reduce the incidence and severity of damage caused by a range of insects, nematodes and fungi.

4.2.3.1 The role of micro, meso and macrofauna in soils

The protozoa and nematodes which are classed as microfauna tend to live in water films on the surfaces of soil and organic particles and in water filled pores. They feed on fungi and bacteria, therefore their contribution to nutrient cycling is dependent on their assimilation of microbial tissue and excretion of mineral nutrients. Microfauna live for short periods and their rapid turnover means that their populations tend to mirror those of the fungal and bacterial populations in soils.

A wide range of organisms including springtails, mites and collembolans can be classed as mesofauna. For many species, their roles in organic matter and nutrient breakdown are poorly understood. Micro-arthropods can consume bacteria, fungi, other soil fauna or a combination of all three, which makes a full understanding of their role difficult to achieve. However, most micro-arthropods assist nutrient mineralisation by feeding on microflora and fauna and by increasing the surface area of plant and faecal material, thereby increasing microbial attack and leaching of water-soluble components.

The term macrofauna encompasses a very diverse group of organisms, the roles of which include: the maceration and burial of organic detritus, which in turn increases its availability to soil microorganisms; the physical rearrangement of soil particles, so changing pore size distribution (which affects infiltration, gas exchange etc.).

Earthworms are the most important form of macrofauna in most temperate agricultural systems and they have been shown to have significant roles in the decomposition of organic matter, subsequent nutrient cycling and in the modification of soil properties (Brown, 1995). Their interaction with microflora and microfauna is of great importance in soil processes and their effects (direct or indirect) include the following:

- Comminution: increases the surface area of residues available for breakdown
- Burrowing and casting: burrows and casts offer ideal environmental conditions for proliferation of micro-organisms
- Selective grazing: affects the population dynamics of micro-organisms
- Organism dispersal: either by survival through the gut or by attachment to the outer surface of the worm

The net effects of earthworm activity are mainly beneficial, for example: reduction of numbers of plant parasitic nematodes and fungi; increased enzymatic activities; spread of biological control agents, AM FUNGIand rhizobia; increased nutrient release. However, under some conditions, earthworms can lead to the dispersal of harmful organisms including parasitic nematodes and fungi.

4.2.3.2 The role of beneficial micro-organisms in soils

The soil microbial biomass (including bacteria, fungi, actinomycetes and microalgae) performs several important functions in the soil. Micro-organisms form a labile source of C, N, P and S; they provide an immediate sink for C, N, P and S; they break down organic matter and are agents of nutrient transformation; they break down soil contaminants such as pesticides. Micro-organisms also contribute towards soil aggregation and structure formation, they form symbiotic associations with plant roots and they can act as biological agents against plant pathogens.

The role of soil organisms is too complex to be dealt with in depth in this review. Beare *et al.* (1995) summarise clearly the role of soil organisms and the importance of biodiversity in the context of nutrient cycling.

4.2.3.3 Soil health

Soil health is central to organic farming, but it's potential has not yet been fully explored. Soil health has physical, chemical and biological components and is concerned with the idea that soil is a living dynamic organism that functions in a holistic way depending upon its condition or state. The biological component of soil health depends on the numbers, diversity and health of the macro, meso and microfauna and microflora present. It 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."

Soil health monitoring is rarely practiced in the UK, but in some parts of the USA, farmers are using test kits to determine chemical, physical and biological components of soil health (http://www.statlab.iastate.edu/survey/SQI/, www.solvita.co.uk). These have proved useful in demonstrating effects of management on soil health (Ditzler and Tugel, 2002). The biological indicators used are earthworm count and soil respiration. It is recognised that soil health depends on more than just these two parameters and that the presence and numbers of specific species are important. However evidence suggests that these basic soil health test kits provide useful guidance to help farmers with soil management decisions.

4.2.4 Key problem relating to crop health in organic farming systems

Lack of effective, economic crop protection strategies is one of the key factors limiting expansion of the organic food and farming industry, particularly where novel or horticultural crops are being considered as part of diversified rotations. There is increasing evidence of the impact which uncomposted materials, composts, manures and compost extracts can have on beneficial microorganisms and pest and disease incidence and severity in agricultural and horticultural crops. The remainder of this review will evaluate this evidence in relation to modern organic agriculture.

4.3 Impact of uncomposted materials, composts, manures and compost extracts on the soil microbial activity

Agricultural practices strongly affect the soil environment and thus are likely to alter soil microbial communities. The beneficial effects of uncomposted materials, composts, manure's and compost extracts are related to improvement of biological fertility of the soil because they promote the development of indigenous soil microbial populations. Microbial soil properties largely determine soil quality and fertility and thus plant establishment and productivity.

4.3.1 Whole soil microbial communities

Microbial activity is fundamental for maintaining soil quality. The biotic fraction of organic matter plays a fundamental role in the soil because it is responsible for the organic matter state and the development and functionality of the soil system. Microorganisms play a fundamental role in establishing bio-geochemical cycles within the soil. Due to the complex dynamics of soil ecosystems, no single property is sufficient for the study of microbial activity. Therefore several parameters need to be examined to establish the overall picture. Parameters often measured include microbial biomass (4.3.1,1), soil labile C (4.3.1.2) and enzyme activities (hydrogenases etc) (4.3.1.3).

4.3.1.1 Soil Microbial Biomass
Microbial biomass C (C_{mic}) can be considered a sensitive indicator of soil quality more than organic matter or total organic C (TOC), since it responds more rapidly to changes. Biomass measurements are early indicators of the response by the organic matter cycle to management changes within soils. The majority of research indicates an increase in C_{mic} upon organic amendment of the soil (e.g. García-Gil *et al*., 2000; He *et al*., 2000) This increase could be attributed to an increase in available C substrates and nutrients, that would in turn stimulate microbial growth. The increase of C_{mic} is not however sustainable and usually declines with time after application of the organic amendment. The decline is probably due to exhaustion of the readily available substrate.

4.3.1.2 Soil Labile C
Soil labile C fractions such as water soluble C and water-soluble carbohydrates also can be considered as indicators of soil microbiological activity. These C fractions are made up of biodegradable substrates and are used by the soil microorganisms as a C and energy source. A negative correlation exists between the level of AM fungal colonisation and the concentration of soluble C fraction (Muthukumar and Udaiyan, 2000; Pearson *et al*., 1994).

4.3.1.3 Soil Enzymatic activities

There is a range of soil enzymatic activities that can be measured. These include:- ureases, proteases, phosphatases and β-glucosidases that provide global measurements of the activity of microorganisms. Enzymatic activities in soil are not only regulated by microbial activity but also by environmental and management factors (such as the addition of organic amendments to soils).

4.3.1.3.1 Soil hydrolases

Measurement of soil hydrolases provides an early indication of soil fertility, since hydrolases are related to the mineralisation of important nutrient elements such as N, P and C. Ureases and proteases play a role in the hydrolysis of organic to inorganic N, the former using urea-type substances and the latter simple peptidic substrates. Phosphatases catalyse the hydrolysis of organic phosphorous compounds to phosphates, while ß-glucosidase hydrolyse ß-glucosides in soil and/or in decomposing plant residues.

Many reports have found that soil hydrolase activities are enhanced by the addition of organic amendments (Dick, 1992; García *et al*., 1998). For example, there is evidence that urease activity in soils can be increased by the addition of organic materials that promote microbial activity (de Caire *et al*., 2000; Lima *et al*., 1996). There are also reports of urease activity being decreased (Benítez *et al*., 2000).

4.3.1.3.2 Soil dehydrogenases

Dehydrogenase activity is involved in the initial breakdown of organic matter and its activity has been proposed as a measure of microbial activity in soils. Several authors have criticized this approach as the enzyme is affected by numerous factors (soil type, pH etc.). Dehydrogenases are among the main endocellular enzymes and take part in metabolic reactions producing adenosine tri-phosphate (ATP) through oxidation and fermentation of glucose. They have been frequently used as an indicator of soil microbial activity (García *et al*., 1997; García *et al*., 2000; García -Gil *et al*., 2000).

Contradictory results have been reported on the effects of addition of organic wastes to soil on soil dehydrogenase activity when using composted manure in comparison with fresh manure. Increases in dehydrogenase activity (Cooper and Warman, 1997; Lima *et al*., 1996) and negative impacts of organic amendments have been made (Serra-Wittling *et al*.,1995).

4.4 Impacts of uncomposted materials, composts, manures and compost extracts on the soil microbial population structure

The structure and metabolic diversity of soil microbial communities have been shown to be affected by agricultural management regimes this includes the impact of organic amendments to the soil microbial community structure and functioning (Bending *et al*., 2002; Díaz-Raviña *et al*., 1996; Frostegård *et al*., 1997; Ibekwe *et al*., 2001; Kokalis-Burelle and Rodríguez-Kábana, 1994; Tiquia *et al*., 2002; Weyman-Kaczmarkowa *et al*., 2002).

A number of studies have used metabolic profiling techniques to investigate the impacts of organic amendments on microbial communities. Such methods characterise substrate utilisation by *in situ* microbial communities or by part of the community that is culturable in Biolog GN microplates to produce community level physiological profiles. These can be used to derive information on 'functional' or metabolic diversity to indicate shifts within the microbial community structure and functioning. Bending *et al*. (2002) demonstrated that Biolog metabolic diversity was affected by the type of organic amendment incorporated into the soil, with a wheat straw treatment having the greatest diversity as compared to the other treatments.

4.5 Impacts of uncomposted materials, composts, manures and compost extracts on beneficial soil microorganisms

The application of uncomposted materials, composts, manures and compost extracts may alter the numbers and population structure of many key beneficial indigenous soil microorganisms. These key microorganisms have an integral role in maintaining soil fertility in relation to plant nutrition. Alterations in the numbers, population structure and functioning of key microorganisms may have serious implications for the growth productivity and disease tolerance for many crop species grown in amended soils. The impact of uncomposted materials, composts, manures and compost extracts on the presence, activity and population of key groups of beneficial soil microorganisms will now be discussed.

4.5.1 Fungi

4.5.1.1 Arbuscular Mycorrhizal (AM) Fungi

Arbuscular mycorrhizal (AM) fungi of the unique phylum *Glomeromycetes* are obligate biotrophs that live symbiotically within plant roots. This ancient symbiosis confers benefits directly to the host plants growth and development through the acquisition of phosphate and other mineral nutrients from the soil by the fungus. The fungus receives its sole C source from the host plant. The symbiosis may also enhance the plants resistance to biotic and abiotic stresses. Additionally, AM fungi develop an extensive external hyphal network, which makes a significant contribution to the improvement of soil structure and functioning.

Organic amendments such as composts, manure’s and compost extracts do not usually contain AM fungal spores and hyphae. The majority of studies have focussed on the effects of organic amendments on the spore and infective propagule density of indigenous populations of AM fungi within amended soil and the subsequent levels of AM fungal colonisation within host plant root systems.

The effects of organic amendments on AM fungal spore densities and colonisation pattern vary greatly and are dependent on many factors. For example, a variety of organic amendments had no effects upon mycorrhizal formation and on AM fungal spore levels (Hafner *et al*., 1993; Leporini *et al*., 1992; Wani and Lee, 1995) while negative effects have been observed on the colonisation levels of AM fungi when their host species was grown in the presence of specific organic amendments (Abdel-Fattah and Mohamedin, 2000). The growth stage of the host plant is particularly important as demonstrated by Baby and Manibhushanrao (1996). Furthermore, Hafner *et al*. (1993) and Mäder *et al*., (2000) found that as the crop matured AM fungal colonisation increased.

The point within the crop rotation at which organic amendments are applied is critical to the response of AM fungal spores, infective propagules and colonisation levels (Baltruschat and Dehne, 1988; Douds *et al*.,1997; Hafner *et al*., 1993; Harinikumar and Bagyaraj, 1988, 1989; Mäder *et al*., 2000). The presence of non-mycorrhizal plant species in a rotation has been shown to depress the levels of AM fungi (Douds *et al*.,1997; Harinikumar and Bagyaraj, 1988). The detrimental effects of organic amendment addition to soil on AM fungi are more pronounced in a continuous monoculture than within a crop rotation (Baltruschat and Dehne, 1988). Baltruschat and Dehne, (1988) demonstrated that in a monoculture of wheat, the negative influences on the inoculum potential by the green manure amendment was observed even with lower N applications.

AM fungi produce a network of external hyphae (extraradical hyphae) that ramifies into the soil matrix and exploits an area of soil beyond the limits of the root system. The hyphal network contributes greatly to soil stability and improves aeration and water percolation. The extraradical hyphal network is responsible for the uptake of mineral nutrients in particular P. Organic amendments have been reported to enhance proliferation of the extraradical hyphae within the soil (St John *et al*., 1983).

The application of sewage sludges can impact on the AM fungal development within the plant root and on the indigenous AM fungal community structure. The impact of non-composted sewage sludges is variable but most often negative due to the high levels of heavy metals present in the sludge (Arnold and Kapustka, 1987; Boyle and Paul, 1988; Höflich and Metz, 1997; Jacquot *et al*., 2000; Kooman *et al*., 1990; Loth, 1996; Loth and Höfner,1995; Sainz *et al*., 1998; Zak and Parkinson, 1983). However, the responses by the AM fungi and host plant are dependent on the type of soil to be amended and the constitution of the sewage sludge to be applied.

Jacquot-Plumey *et al*. (2001) demonstrated that the application of composted sewage sludge modified the AM fungal community. Development of some of the AM fungal isolates was stimulated in the plant roots by the addition of composted sewage sludges. Sewage sludge spiked or not with organic pollutants had a generally positive effect on the relative diversity of AM fungal populations *in planta*. Whereas, after spreading of sewage sludge spiked with metallic pollutants, no variation was observed in the abundance of different species. The modification of the natural communities of AM fungi by composted sewage sludge will depend on the composition of the sludge and the soil to be amended.

The growth responses observed when plants are grown in soils amended with composts, sludges etc. may result from the presence and abundance of specific isolates of AM fungi. Several studies show that AM fungi alter (non-agricultural) plant community structure by affecting the relative abundance and diversity of wild plant species. Muthukumar and Udaiyan (2002) demonstrated that the plant response to organic amendments was strongly correlated to changes in mycorrhizal colonisation levels and specific population of spores, thus suggesting that the differential response to the organic manures is related to the specific isolate(s) of AM fungus present within the soil.

Studies have shown that plant root systems colonised by AM fungi differ in their effect on the bacterial community composition within the rhizosphere and rhizoplane, with the number of facultative anaerobic bacteria, fluorescent pseudomonads, *Streptomyces* spp. and chitinase producing actinomycetes differing in numbers depending on the host plant and isolate of AM fungus. Abdel-Fattah and Mohamedin, (2000) demonstrated that the total number of bacteria, fungi and actinomycetes changed in the rhizosphere of mycorrhizal and non-mycorrhizal plants grown in chitin amended soil. Addition of chitin to soils is known to promote the activity and numbers of rhizosphere microflora, However, Abdel-Fattah and Mohamedin, (2000) demonstrated that in AM fungal colonised plants grown in chitin amended soils the number of rhizosphere bacteria increased, while the number of fungi and actinomycetes significantly decreased.

Inoculation of AM fungi into crops or soils amended by compost on farms may positively affect vegetable crop production (Gaur and Adholeya, 2000). Three vegetable crops *Coriandum sativum* (coriander), *Trigonella foenumgraecum* (fenugreek) and *Daucus carota* (carrot) were inoculated with AM fungi and grown in nutrient deficient soils amended with organic matter. The increase in crop yield was greater in plots amended with leaf compost added in equal volumes to that of the soil in the top 20 cm than those amended with double that quantity of compost. The crop species differed in the level to which they were colonised by AM fungi and infective AM fungal propagules were produced in greater numbers on coriander and fenugreek (Gaur and Adholeya, 2000).

4.5.1.2 Ectomycorrhizal Fungi

Ectomycorrhizal associations are mutualistic associations between higher fungi and gymnosperm and angiosperm plants of specific plant families, in particular tree species such as *Betulaceae, Leguminosae* and *Pinaceae* etc. The use of uncomposted materials, composts, manure's and compost extracts is important within afforestation programs. Organic amendment as practiced during afforestation of soils has been shown to benefit growth, development and survival of plants, in particular *Pinus halepensis* (García *et al*., 1998). Moreover, inoculation with ectomycorrhizal fungi along with addition of organic materials has a positive influence on soil microbial activity and soil aggregate stability (Caravaca *et al*., 2002; García *et al*., 2000).

4.5.1.3 Nematode trapping fungi

Nematode trapping fungi are facultative fungi that form mycelial structures to trap nematodes. Some trapping fungi can proliferate in the soil in the absence of nematodes while others are more dependent on nematodes as a nutrient source. Organic amendments to soils have been shown to stimulate specific nematode trapping fungi (Cooke, 1962; Dackman *et al*., 1987; Duponnis *et al*., 2001; Jaffee *et al*., 1998) although in some cases they suppress the fungi (Jaffee *et al*.,1994). The majority of studies on the impact of organic amendments showed a positive influence on population density but Jaffee (2002) also demonstrated an enhanced functional activity within the nematode trapping population.

Negative effects on populations of nematode trapping fungi can be related to the chemical composition of particular amendments, in particular, green manures. Lopez-Llorca and Olivares-Bernabeu (1997) demonstrated that water extracts from *Quercus* leaves and leaf litter with high phenolic contents were inhibitory to the growth of nematophagous and entomopathogenic species.

4.5.1.4 Trichoderma species

Trichoderma spp. are known biological control agents of many plant-pathogenic fungi. They have a range of attributes which make them particularly potent biological control agents within soil. For example, they capable of mycoparasitism, they are aggressive competitors for nutrients and producers of chemical agents such as antibiotics. Soils with organic amendments have been shown to have significantly higher propagule densities of *Trichoderma* sp. than those soils amended with synthetic fertilisers regardless of production system history (Bulluck *et al*., 2002; Bulluck and Ristaino, 2002).

4.5.2 Nematodes

4.5.2.1 Bacterivorous and fungivorous nematodes

Nematodes play a major role in decomposition and nutrient cycling in soil food webs and are abundant in terrestrial and aquatic ecosystems. Although nematodes represent a relatively small amount of biomass within soil, their presence across many trophic levels in soils is vitally important within the soil environment and ecosystem processes. Populations of bacterivorous and fungivorous nematodes tend to increase after organic amendments (Bongers and Ferris, 1999; Bouwman and Zwart, 1994; Bulluck *et al*., 2002; Jaffee *et al*., 1998; McSorley and Gallaher, 1996; Porazinska *et al*., 1999; Riegel and Noe, 2000). Increased populations of bacterivorous nematodes can be linked directly to higher populations of bacteria associated with the input of organic amendments (Bulluck and Ristaino, 2001).

4.5.3 Bacteria

4.5.3.1 Nitrogen Fixing Microorganisms

Many leguminous species have the ability to fix atmospheric N through symbiotic association with several bacterial genera belonging to the *Rhizobiaceae*, all of which may be referred to by the term ‘rhizobia’. N fixation takes place in a specialised organ the nodule and is the result of a complex interaction leading to a finely tuned symbiosis between plant and compatible rhizobia. The bacterium encodes the basic enzymatic machinery for converting molecular N into ammonium, plus a number of genes required for the symbiosis. The plant provides the microenvironment necessary for carrying out N fixation and contributes enzymes that assimilate the fixed N. In agronomic terms the potential benefit of symbiotic N fixation of leguminous plants is enormous as the symbiosis can produce N yield of 100-300 kg N ha^{-1} yr^{-1}. The free living N fixing microorganisms are estimated to contribute 1-3 kg N ha^{-1} yr^{-1}, therefore, it is particularly important to understand the effects of uncomposted materials, composts, manure’s and compost extracts on symbiotic and free living N fixing microorganisms.

Few studies have been conducted on the effects of organic amendments on symbiotic N fixation and the effects are variable depending on host plant, type of amendment and environmental conditions (Heckman and Kluchinski, 1995; Keeling and Cook, 1999; Lodha and Burman, 2000; Muir, 2002; Ramos and Boddey, 1987; Rosemeyer *et al.*, 2000;). The application of composts on the rhizobial population structure may affect the population structure of the indigenous *Rhizobial* population (Cousin *et al*., 2002).

Sewage sludge contains a variety of materials that are potentially toxic to rhizobia, including soluble salts, heavy metals and synthetic organics. N fixation by *Rhizobium leguminosarum* bv. *Trifolii* in symbiosis with *Trifolium repens* has been found to be affected by the presence of heavy metals in sludge amended soils (Giller *et al*., 1988; McGrath *et al*., 1988). Despite the potential of metal contaminated sewage sludge to have harmful effects on the populations of *Rhizobia*, beneficial effects have been observed as sewage sludge also contains numerous components required for rhizobial growth and survival (Madariaga and Angle, 1992; Obbard *et al*., 1993).

Alder trees (*Alnus* spp.) have root nodules in symbiosis with actinomycetes of the genus *Frankia*, that have the ability to fix atmospheric N. Economically, alders are important in reforestation and reclamation of N depleted, N limited soils. They are also used as nurse trees in mixed plantations with valuable tree species such as walnut. The efficiency of the symbiosis between *Frankia* and alder species is largely determined by environmental parameters of the soil. Nickel *et al.* (2001) demonstrated that leaf litter amendment to the soil altered the population structure of nodule forming *Frankia* populations within the soil.

The impact of organic amendments on free-living N fixing microorganisms was investigated by Hegazi *et al*., (1986) and Ishac *et al*., (1986). Amendment of soil with residues of wheat and maize crops together with flood irrigation enhanced the development of free-living N fixing microorganisms and nitrogenase activities within the soil (Hegazi *et al*., 1986).

4.5.3.2 Plant growth promoting rhizosphere bacteria (PGPR)

Plant growth promoting rhizosphere bacteria (PGPR) benefit the growth and development of plants through several mechanisms, for example:- the production of secondary metabolites; the production of siderophores; antagonism to soilborne root pathogens; phosphate solubilisation and dinitrogen fixation. The establishment in the rhizosphere of microorganisms possessing these characteristics is important for the health and development of plants.

Mature composts provide a rich medium capable of supporting high microbial activity and a diverse microbial population. Application of composts to soils affects the PGPR microbial populations within the rhizosphere of plants depending upon the type of compost used (de Brito Alverez *et al*., 1995). Effects on the PGPR population include significant increases in siderophore producers. Siderophores are believed to contribute to pathogen inhibition. However, no differences were observed in siderophore producers within the phylloplane of winter wheat grown in soils amended with straw and/or cattle manure (Rodgers-Gray and Shaw, 2001).

4.5.3.3 Fluorescent Pseudomonas species
Fluorescent pseudomonads are among the most numerous bacteria found on plant surfaces and can suppress plant diseases through direct antagonism and the production of siderophores. Other mechanisms such as such as induction of a systemic resistance and the production of hydrolytic enzymes play a role in their suppression of diseases. Soils with organic amendments have been shown to have higher numbers of fluorescent *Pseudomonas* species. (Aryantha *et al*., 2000; Bulluck and Ristaino, 2002).

4.5.3.4 Actinomycetes
Soil actinomycetes are widely distributed within soils and may account for a large proportion of the soil microbial population. Actinomycete numbers have been shown to fluctuate within soils amended with organic substrates. Aryantha *et al*. (2000) reported a positive effect while Miyashita *et al*. (1982) demonstrated an initial suppression then recovery in the numbers within the soil. Actinomycetes when isolated from organic mulches have been shown to suppress plant pathogens such as *Phytophthora* species (Lodha and Burman, 2000; You and Sivasithamparam, 1996; You *et al*., 1996;).

4.5.3.5 Ammonia oxidising bacteria
Autotrophic ammonia oxidising bacteria (AAO) of the β-group proteobacteria are important in the N cycle of arable soils as they are responsible for the majority of ammonia oxidation, the initial and rate limiting step in nitrification. The study of Mendum and Hirsch (2002) demonstrated the alteration within the community structure of autotrophic ammonia oxidising bacteria in arable plots that had been amended with farmyard manure and NH_4NO_3 fertiliser.

4.6 Impact of uncomposted materials, composts, manures and compost extracts on pests and disease causing organisms

Effective control of economically important plant pests and diseases in conventional farming systems is achieved through a combination of cultural practices and chemical pesticides. Due to the pressure on farmers and policy makers to use less pesticides and to turn to more environment-friendly farming practices including organic farming, there is increasing interest in the potential of cultural methods including the application of composts and manures for control of pests and diseases. Composts, manures and uncomposted plant materials have been applied to agricultural land world-wide for centuries, but their deliberate application for the purpose of preventing and controlling plant pests and diseases is a more recent phenomenon.

The majority of recent work relating to the use of uncomposted materials, composts, manures and compost extracts for prevention and control of pests and diseases relates to container-produced plants and most of that concerns ornamentals. However, there is increasing interest in the potential for use of composts and similar materials for preventing and controlling pests and diseases in field crops and information concerning their use is slowly increasing. There is very little published information on the effects of composts on pest and disease control on organic farms, therefore this review will discuss research carried in pot and field experiments relating to both conventional and organic agriculture.

4.6.1 Effect of uncomposted plant residues on pests and diseases

Much of the work on the effects of uncomposted plant residues on pests and diseases relates to the use of cover crop residues to reduce the incidence and severity of plant parasitic nematodes. However there is a limited amount of information on the impact of crop residues (including those of cover crops) on plant diseases.

Cover crops are typically grown during the off-season following the production of a cash crop. They are particularly common in organic systems, where the regulations recommended that the soil is not left bare for extended periods due to the need to preserve soil structure and prevent nutrient leaching. Cover crops are usually ploughed in prior to planting the next cash crop and when they are ploughed in they are usually termed "green manures".

Cover crops have been shown to increase soil organic matter, microbial activity (Cook and Baker, 1983) and they have also been shown to reduce or suppress plant diseases (Abawi and Crosier, 1992; Sumner and Boosalis, 1981; Viane and Abawi, 1998). For example, foliar diseases on tomato caused by *Alternaria solani* and *Septoria lycopersicae* were significantly reduced (in comparison with untreated controls) in plots covered with a hairy vetch green manure crop (Mills *et al*., 2002). In this instance, the reduction in foliar disease was attributed to reduced splash dispersal of spores due to the mulch-covered soil surface.

The impact of crop residues from green manures on crop health and plant disease incidence is however, highly variable depending on the type of crop residue, the crop and cropping system, soil type, climate etc. For example, results of glasshouse tests on field beans showed that green manures of a range of cover crops tested differed significantly in their suppression of root-rot and damage to bean growth (Abawi and Widmer, 2000). Differential effects of green manures from various cover crops on bean yield and the severity of root rot have also been observed under field conditions. For example, when a cover crop of grain rye was incorporated as a green manure, the bean yield was significantly greater and and root-rot severity was less than that recorded on beans with no preceding crop. However beans grown with a hairy vetch green manure crop showed a lower yield than the control and a higher incidence of root rot (Abawi and Widmer, 2000). There has been insufficient work done to allow reliable prediction of the effects of different green manures on crop yield and plant disease incidence and severity.

A range of other crop residues (i.e. not derived from cover crops) have been tested with a view to determining their effects on crop yield and plant disease incidence and severity. The results of these tests have been highly variable. For example, citrus pulp with molasses significantly reduced the severity of disease caused by *Phytophthora capsici* on bell pepper and increased crop growth, but citrus pulp alone did not have the same effect. (Kim *et al*., 1997). In a different experiment, the addition of grass mulch to the surface of soils used for the production of bean significantly reduced the number of germinating sclerotia of *Sclerotinia sclerotiorum* (Ferraz *et al*., 1999). The greatest reduction in sclerotial germination occurred in the deepest of four mulch depths (9 cm). However, crop growth and yield was reduced in the deepest mulch and was optimal in a mulch layer of 6 cm.

There has been a significant amount of work carried out to show that uncomposted plant residues can suppress plant parasitic nematodes. For example, olive pomace has been shown to reduce numbers of root-knot nematode (*Meloidogyne javanica*) in the roots of glasshouse-grown tomato and pepper (Marull *et al*., 1997). Similarly, Mojtahedi *et al*. (1991) showed that root-knot nematode populations were suppressed when certain rapeseed cultivars were used as a green manure. However, control of nematodes using uncomposted plant residues is highly dependant on the use of an appropriate type of residue in a suitable soil and cropping system. The degree of control achieved rarely approaches the efficacy achieved using commercially available nematicides and is often highly variable.

The work done to determine the effects of uncomposted crop residues on crop yields and pest and disease incidence and severity has been fragmented. Much of it has been done in warmer climates than the UK, in different soil types and locally available residues have been used which may not be available elsewhere. A great deal of work needs to be done to determine the effects of crop residues available in the UK on pest and disease incidence in UK organic crops and cropping systems.

4.6.2 Effect of composts on pests and diseases

4.6.2.1 Effect of composts on pests

Documentation of the effects of composts on plant pests relates almost exclusively to the suppression and control of plant parasitic nematodes. There has been considerable progress in the use of composts as soil amendments for the control of plant parasitic nematodes in field soils and many studies report reductions in nematode numbers following compost application (Akhtar and Malik, 2000). For example, the roots of green peppers and tomatoes grown in soils amended with municipal compost residues contained lower numbers of root-knot nematode (*Meloidogyne javanica*) than those grown in unamended soils (Marull *et al.,* 1997). Similarly, yard waste compost applied to field soils in Florida was shown to be associated with increased maize yield and a reduction in populations of several species of parasitic nematode including *Paratrichodorus minor, Criconomella* spp. and *Pratylenchus* spp. (McSorley and Gallaher, 1995b. Chen *et al*. (2000) found that the application of brewery compost reduced root galling severity and egg production of *Meloidogyne hapla* and increased yield of lettuce by 13 % in fumigated soil and 23% in non-fumigated soil.

However, as with manures and uncomposted plant residues, the use of composts to prevent and control plant-parasitic nematodes has been shown to have highly variable results. Several workers have reported no effects or variable effects of composts on nematode populations. For example McSorley and Gallaher (1997) reported that the effects of yard waste compost on populations of plant-parasitic nematodes including *Mesocriconema* spp., *Meloidogyne incognita* and *Pratylenchus* spp. were inconsistent.

Much of the variability between reports from different research workers may be due to differences in experimental technique, soil type, climate and farming system, but there are also marked differences between the feedstocks used to produce compost and the composting system. It is acknowledged that the application of composts will rarely, if ever give control comparable with that achieved through the use of chemical nematicides. However, an increasing number of farmers are prepared to accept lower levels of control in return for lower input costs and more sustainable production systems including organic systems. Most of the work relating to the control of nematodes has been carried out in warmer climates than the UK, in soil types which do not exist here. A great deal of further work is required to develop reliable integrated control systems for plant-parasitic nematodes which can be used in UK organic and sustainable farming systems.

4.6.2.2 Effect of composts on diseases

During the late 1960's, nurserymen in the United States began using composted tree bark as a substitute for peat to reduce the cost of growing media. It was quickly found that the growth of ornamental plants was improved and crop losses due to disease were reduced as a result of using the composted bark instead of peat (Hoitink *et al.*, 1997). It is now recognised that the control of root rots caused by some plant pathogens (e.g. *Phytophthora* and *Pythium*) on plants grown in compost-amended substrates can be as effective as if they were treated with modern synthetic fungicides (Ownley and Benson, 1991).

The suppressive activity of certain types of compost towards plant pathogens is now well documented. The most predictable and successful pathogen suppression has been reported in container production systems in the United States (Hoitink and Fahy, 1986; Hoitink and Stone, 1997; Nelson and Craft, 1992). There are increasing examples of disease suppression following application of composts to field soils, but our understanding of the mechanisms behind suppression in field soils is less well developed than that in container production systems. There is considerable inconsistency in the level of disease suppression reported in field soils, probably due to the different experimental conditions and differences in compost types used. Most research on the effects of composts on plant pathogens focuses on the three root and soilborne pathogens *Rhizoctonia, Pythium* and *Phytophthora* spp., but work also covers other pathogens including *Sclerotinina, Thielaviopsis, Fusarium, Verticillium, Mycosphaerella* and *Macrophomina* spp.

4.6.2.2.1 Suppression of diseases in container production systems

The concept of using composted hardwood bark as a peat substitute to control soilborne pathogens was first suggested by Hoitink (1980). This compost was shown to suppress several soilborne plant pathogens including *Phytophthora, Pythium* and *Rhizoctonia* spp. which cause damage to plants grown in container media (Nelson *et al*., 1983; Spring *et al*., 1980). It has since been shown that the type of bark used as feedstock, the composting system used and the other components of the container medium are all critically important in determining its suppressiveness. For example the addition of older, more humified peats to composted bark (a common practice in container production) reduced or eliminated it's suppressiveness (Boehm and Hoitink, 1992). The maturity of the bark compost has been shown to affect the degree of suppressiveness (Nelson et al., 1983). The temperature zone within the compost pile from where the composted hardwood bark is taken has also been shown to affect suppressiveness of the container medium (Chung and Hoitink, 1990). A considerable amount of work has been done to develop container media containing composted bark for different crops and production systems. This media is now widely used either exclusively or as part of an integrated strategy to prevent and control root and soilborne pathogens of container produced ornamental plants in the United States. However, such practices are little understood and rarely used by UK ornamental growers.

The pressure to reduce pollution and volumes of industrial and domestic waste to landfill has resulted in the need for new systems to treat wastes. This in turn has resulted in greater availability of a wide range of wastes and compost types including those containing sewage sludge and municipal solid wastes. Much of the early work to develop uses and markets for these materials was done in the United States on ornamental container production systems.

Composts made from a very wide range of feedstocks have been tested for their potential as components of container media and many of these composts have been shown to aid in the prevention or control of root and soilborne diseases. For example, *Rhizoctonia solani* and *Sclerotium rolfsii* were suppressed in container media containing composted separated cattle manure and composted grape marc (Gorodecki and Hadar, 1990). *Pythium aphanidermatum* damping-off was suppressed in container media containing composted liquorice roots (Hadar and Mandelbaum, 1986) and disease caused by *Pythium ultimum* and *Rhizoctonia solani* was considerably reduced in container media amended with composted organic household wastes (Schueler *et al*., 1989). Composts based on municipal sludge/sewage sludge have also been shown to suppress a range of soilborne and root diseases caused by pathogens including *Pythium*, *Rhizoctonia* and *Fusarium* when used as components of container media (Kuter *et al*., 1988; Serra-Wittling *et al*., 1996). Composts made from agricultural wastes, household greenwastes and municipal sludges are now used in the United States as components of container media for production of container-grown ornamentals and their role in the prevention and control of soil-borne disease is recognised there. A very few UK nurserymen are using composted agricultural wastes and by products as components of growing media for ornamental plants, but the main reason for doing so is to reduce reliance on peat, rather than for prevention of root disease.

It is recognised that the suppressiveness of individual composts as components of container media may not be replicated in field soils. However the large body of information which has been built up in container media trials could provide useful indications of which composts may help confer suppressiveness to field soils. Table 4a shows examples of pathogens which have been suppressed either wholly or partially on given crops with compost prepared from known feedstocks. The results were obtained from research carried out by different workers from several countries under different experimental conditions including indoor and outdoor container or pot trials and in field soils, but they do give an indication of which feedstock types may be considered for some crop/disease applications.

4.6.2.2.2 Suppression of disease in field soils

There is an increasing body of evidence to show that some types of compost can partly or wholly suppress pathogens and/or soil-borne disease in some field soils and production systems. For example, amendment of soil with compost made from residues of pearl millet (*Pennisetum glaucum*), neem and weeds reduced resident populations of *Macrophomina phaseolina* (which causes dry root rot of legumes) by 20 - 40% in comparison with unamended controls (Lodha and Burman, 2000). Application of cattle manure composts to soils significantly reduced the incidence of organic potato tubers infected with black scurf caused by *Rhizoctonia solani* (Tsror [Lakhim] *et al*., 2001). Amendment of field plots with composted sewage sludge (7-10 t ha^{-1}) significantly reduced the incidence of damping-off of smooth skinned and wrinkled pea cultivars caused mainly by *Rhizoctonia solani* and *Pythium ultimum* (Lewis *et al*., 1992).

As with all work to determine the effects of composted and uncomposted organic residues on plant diseases, the results are highly variable depending on the feedstocks used, the climate and soil and the production system in question. Much of the published work has been done in tropical or mediterranean climates in soil types not represented in the UK and on crops not grown in the UK. None of the work on municipal solid wastes and sewage sludge is directly applicable to organic farming systems, since these amendments are prohibited under the EU organic regulations. There is great potential to develop successful integrated organic disease control disease systems based wholly or partly on the use of composts made from a wide variety of sources. Valuable information can be gained from a detailed study of the research work which has demonstrated successful control of plant pathogens through the use of composts. However, considerable research and development work is required to develop systems appropriate to organic crops in the UK climate, soils and production systems.

Table 4a. Examples of proven plant disease suppression following application of composts made from known feedstocks

Target pathogen	Crop	Principal feedstock(s) in compost
Aphanomyces euteiches	pea	cattle manure
Botrytis cinerea	strawberry	MSW 'tea'
	bean	
Erisyphe graminis	barley	MSW 'tea'
	wheat	
E. polygoni	phaseolus bean	MSW 'tea'
Fusarium oxysporum	cucumber	dairy solids
	flax	MSW
	melon	sewage sludge
	nursery stock	cattle manure
	tomato	chicken manure
	radish	MSW
	sweet basil	bark
F. culmorum	wheat	greenwaste
Macrophomina phaseolina	legumes	pearl millet, neem, weeds
Phoma medicaginis	peas	greenwaste
		paperwaste
Plasmodiophora brassicae	cabbage	spent mushroom substrates (SMS)
		greenwaste
		paperwaste
Phytophthora cinnamomi	white lupin	chicken manure
	nursery stock	pine bark
	sweet basil	vegetable waste
	lupin	citrus
P. capsici	sweet pepper	vegetable waste, sewage sludge
P. fragariae	strawberry	greenwaste
		paperwaste
P. infestans	tomato	MSW 'tea'
	potato	
P. nicotianae	pea	greenwaste
	tomato	biosolids
	cucumber	MSW
	lupin	citrus
Pythium ultimum	cucumber	pine bark, cattle manure/leaves
	nursery stock	poultry manure/leaves
	chrysanthemum	bark
	pea	grape marc
	sugar beet	MSW (organic fraction)
	iris	greenwaste, biosolids
P. graminicola	creeping bent grass	MSW, brewery waste, biosolids, poultry manure
P. myriotylum	bean	MSW
	cucumber	MSW
	tomato	greenwaste
	watermelon	papermill sludge, SMS
P. irregulare	cucumber	MSW, greenwaste
P. aphanidermatum	cucumber	MSW, greenwaste, sugarcane, liquorice root

Target pathogen	Crop	Principal feedstock(s) in compost
Rhizoctonia solani	bean	biosolids
	cucumber	harwood bark
	nursery stock	cattle manure
	potato	cattle manure
	radish	vegetable waste
	tomato	poultry manure
Sclerotinia minor	lettuce	sewage sludge
		biosolids
		grape marc
Sphaerotheca fuliginea	cucumber	MSW 'tea'
Venturia inaequalis	apple	SMS 'tea'

4.6.3 Effect of manures on pests and diseases

There has been a great deal of work carried out to determine the effects of manures on soil fertility and crop growth and yield, but considerably less to determine the effects of manures on disease incidence and severity. Unlike mature composts, fresh manures do not provide an ideal environment to support a wide range of beneficial organisms and therefore they will not contribute the same breadth of microbial species to the soil when they are ploughed in. However, they have been shown to enhance suppression of soilborne diseases in a few cases. For example, damping-off of radish and lesion development caused by *Rhizoctonia solani* was reduced in plot experiments where manure was added in comparison with non-amended controls (Voland and Epstein, 1994). Similarly, fresh chicken manure has been shown to reduce survival of the pathogen *Phytophthora cinnamomi* and the incidence of symptoms on *Lupinus albus* seedlings (Aryantha *et* al., 2000).

Manures have been shown to reduce populations of plant-parasitic nematodes and damage caused by them. For example, Van der Laan (1956) reported that the addition of farmyard manures reduced populations of *Heterodera rostochiensis* in potato roots. Similarly, steer and chicken manures reduced the numbers of cyst and citrus nematodes and resulted in increased yields of citrus and potatoes (Gonzalez and Canto-Sanenz, 1993).

The impact of manures on pest and disease incidence and severity is less predictable than that of composts. Several workers have shown that the application of manures to soils can increase the incidence and severity of pests and diseases (Aryantha *et* al., 2000.) Available evidence suggests that composts are likely to give more predictable, consistent control of plant pests and diseases and that research efforts would be better directed towards developing composts as aids to crop protection in organic systems, rather than manures.

4.6.4 Effect of compost extracts and teas on diseases

Sprays based on compost extracts have been used for hundreds of years. There is evidence that the Romans used compost teas and the ancient Egyptions used preparations based on compost or manure extracts as long as 4000 years ago, although, not surprisingly, there are no records of how these were made! (Cascadia Consulting Group, 2001). Interest in compost extracts and teas waned when pesticides became available in the 20th century, since pesticides tend to give better, more reliable control of most foliar diseases. However, the recent increase in sustainable and organic farming and problems relating to pesticide use has led to a massive resurgence in interest in compost extracts and teas. A considerable amount of work has been carried out to develop improved methods for preparation and use of compost extracts and teas. Most of this work has been done in the United States and much of it by commercial companies rather than federal research institutes. The work and the key findings from it are discussed below.

There is some confusion as to exactly what is meant by compost teas and compost extracts. Numerous terms have been used to describe the product of compost fermentations and each of these needs to be properly defined.

The term "compost tea" is used in this review to describe the product of showering recirculated water through a porous bag of compost suspended over an open tank with the intention of maintaining aerobic conditions (Riggle, 1996). The product of this method has also been termed "aerated compost tea" and "organic tea". Several commercial companies have developed machinery for the preparation of teas in this way under highly aerated conditions and all refer to the end product as compost teas.

In the past, the term "compost tea" has not always been associated with an aerated fermentation process (Brinton *et al*., 1996). It is important to distinguish between compost teas prepared using aerated and non-aerated processes, therefore the terms aerated compost tea (ACT) and non-aerated compost tea (NCT) will be used in this review to refer to the two dominant compost fermentation methods. ACT will refer to any method in which the water extract is actively aerated during the fermentation process. NCT will refer to methods where the water extract is not aerated or receives minimal aeration during fermentation apart from during the initial mixing.

The term "compost extract" has been used in the past to define water extracts prepared using a very wide range of different methods (Scheuerell and Mahaffee, 2002a). In the past, the terms compost extract, watery fermented compost extract, amended extract, compost steepage and compost slurry have all been used to refer to non-aerated fermentations. "Compost extract" (Weltzein, 1989), "watery fermented compost extract" (Weltzein, 1991) and "steepages" (Hoitink *et al*., 1997) are approximate synonyms defined as a 1:5 to 1:10 (v:v) ratio of compost to water that is fermented without stirring at room temperature for a defined length of time. "Amended extracts" are compost extracts that have been fermented with the addition of specific nutrients or microorganisms prior to application (Weltzein, 1991). The term "compost slurry" has been used to describe non-aerated compost teas before the filtration process (Cronin *et al*., 1996). Brinton *et al*. (1996) defines compost extracts or teas as a "deliberate production of specific (water) extracts based on composts of known properties and age". He does not distinguish between aerated and non-aerated preparation. For the purposes of clarity in this review, the term compost extract refers to the filtered product of compost mixed with any solvent (usually water), but not fermented.

4.6.4.1 Methods for producing compost teas

The production of aerated and non-aerated compost teas both involve compost being fermented in water for a defined time period. Both methods require a fermentation vessel, compost, water, incubation and filtration prior to application. Nutrients may be added prior to or following fermentation and additives or adjuvants may be added prior to application.

There is vigorous ongoing debate regarding the benefits of aeration during compost tea production (Brinton *et al*., 1996; Ingham *et al*., 1999, 2000). Aerated production methods are associated with shortened production time. Nonaerated methods are associated with low cost, low energy input and many documented reports of successful plant disease control (Weltzein, 1991). Several consultants and scientists have suggested that NCTs can cause phytotoxicity and that the production of NCTs provides an ideal environment for the growth and reproduction of human pathogens, however there is limited evidence to prove either of these claims at present.

The design of machinery which facilitates preparation of aerated compost tea varies. Designs include:

- showers of recirculated water which filter through bags of compost suspended over open tanks (Riggle, 1996)
- recirculated water which is directed through a vortex nozzle held above a tank (Ingham and Alms, 1999)
- injection of air through various distribution channels including a hollow propeller shaft (Soilsoup.com), venturi nozzles (Composttea.com) or fine bubble diffusion mats (Growingsolutions.com).

Several companies now offer fermentation units that produce aerobic compost tea by suspending compost in a fermentation vessel and aerating, stirring or recirculating the liquid (Diver, 2001).

NCT has generally been made by mixing one volume of compost with between four to ten volumes of water in an open container. The mixture is stirred as it is made up, then it is left for at least 3 days at 15-20^{o}C with minimal or no stirring (Brinton *et al*., 1996; Weltzein, 1991). Compost teas can be made in quantities ranging from a few litres to several thousand litres in a single batch depending on the size of the fermentation vessel.

4.6.4.2 Effect on plant disease

Compost teas have been shown to help prevent and/or control a wide range of foliar diseases in glasshouse and field grown edible and ornamental crops. A comprehensive account of diseases which have been fully or partially controlled through the application of compost teas or extracts under experimental conditions is given in Scheueller and Mahaffee (2002a). Examples of diseases controlled in this way include *Alternaria* spp., *Botrytis cinerea, Phytophthora infestans, Plasmopara viticola, Sphaerotheca* spp., *Uncinula necator* and *Venturia inaequalis*. Control has not been achieved with all pathogens in all tests. Efficacy varies depending on the crop and experimental system.

Most of the published evidence to demonstrate control of foliar disease concerns NCTs or compost extracts. At present, there is a shortage of data which compares the efficacy of ACTs and NCTs in controlling foliar diseases. A study by Scheueller and Mahaffee (2002b) examined the role of aeration and three different compost types on the efficacy of compost teas for controlling powdery mildew (*Sphaerotheca pannos* var. rosae) on rose. All six compost teas significantly reduced powdery mildew in comparison to a control spray of water, but there was no difference in efficacy between ACTs and NCTs.

There are now several commercial companies in the United States which are selling and promoting the use of machinery to make ACT's. However there has been only limited work to demonstrate the efficacy of ACT's and there is little scientific evidence to show that they are any more effective in controlling disease than NCTs. The limited number of controlled studies which have been carried out to date are summarised in Scheueller and Mahaffee (2002a). Trials on a range of crops have shown that the effects of ACTs vary considerably. For example, no effect of ACT applications on early blight of tomato was observed; lettuce drop (several pathogens) was reduced in a summer but not a spring crop; post-harvest fruit rot of blueberries was significantly reduced, but this was offset by reduced yields. In conclusion, the impact of ACTs on plant health and crop yield can be crop specific and may depend on the experimental system and environmental conditions. General statements about the efficacy of ACTs cannot be made.

Compost teas are also being widely advertised and used on both organic and conventional farms (mainly in the United States) as an inoculant to restore or enhance soil microflora (www.attra.ncat.org). However very little work has been done to quantify the benefits from using compost teas in this way. There has been some work carried out to determine the effects of NCTs on seedborne pathogens through seed treatment (Tränkner, 1992). There has also been limited work done on soilborne pathogens in vitro (Weltzein, 1991), but it is well known that successful disease control *in vitro* does not always translate to field conditions. Recent work has shown that fusarium wilt of pepper (*F. oxysporum* f.sp. *vasinfectum*) and cucumber (*F. oxysporum* f.sp. *cucumerinum*) was controlled by drenching NCT on to soil under greenhouse conditions (Ma *et al*., 2001). The mode of action of the NCT was investigated *in vitro* and it had a mycolytic effect on fusarium microspores and chlamydospores, which showed that destruction of the pathogen propagules could be important in disease suppression

4.6.4.1 Potential problems with compost extracts and teas
At present, the main potential problem with compost teas (apart from reports of variable efficacy in controlling plant disease) appears to be the concern that fermenting compost could potentially support the growth of human pathogens. For example, Welke (1999) detected faecal coliform and salmonella populations in the source compost, the NCT fermentation and on samples of broccoli and leek growing in a field and sprayed with the NCT. Present evidence shows that pathogens can grow during the production of both ACTs and NCT's. However, the indications are that pathogen growth is not supported when ACTs or NCTs are prepared without fermentation nutrients (Scheuerell and Mahaffee, 2002a). Further work is required to ensure that the production and use of compost teas and extracts can be guaranteed not to propagate and spread human pathogens onto food intended for human consumption.

<u>4.6.5 Mechanisms of control and factors affecting control of diseases using uncomposted materials, composts, manures and compost extracts</u>

Sufficient information has now become available on the disease suppressive properties of composts to allow predictable biological control of diseases in some crop production systems. In particular, reliable control of *Pythium* and *Phytophthora* spp. can be achieved in container production systems, where the optimum chemical and physical properties of growing media have been documented and tested in detail (Hoitink and Fahy, 1986; Nelson *et al*., 1983; Ownley and Benson, 1991). However, some workers have reported poor disease control or increased disease following the application of composts. For example, use of composts prepared from heterogeneous wastes that vary in salinity, N availability and degree of decomposition composting may lead to marked increases in disease incidence and severity. Such composts cannot be used with predictable efficacy. Quality control of composts is therefore of prime importance in the field of biological control of plant pathogens. It is known that the feedstocks used, the composting process and the maturity of the compost are all critical in determining the disease suppressive properties of the finished compost product.

The following factors have been identified as determinants of success in biological control of plant pathogens with composts. Firstly, the feedstock type(s), the composting system and the level of compost maturity are important. Secondly, the chemical and physical attributes of the compost affect the activity of the beneficial and pathogenic organisms and the susceptibility of the host plant to disease. Thirdly, the fate of plant pathogens and biological control agents during the composting process is important. Finally, the biology of the finished compost is of critical importance in determining its suppressivity.

Four mechanisms have been described for the activity of biocontrol agents against soilborne plant pathogens. They are: (1) competition for nutrients (C and/or iron), (2) antibiosis, (3) hyperparasitism and (4) induced protection (Hornby, 1990). Most reports of disease suppression suggest that microbiostasis (i.e. competition and.or antibiosis) and hyperparasitism are the principal mechanisms. Mechanisms of disease suppression can be divided loosely into two general categories described as "general" and "specific" (Baker and Cook, 1974). The term "general" applies where disease suppression can be attributed to the activity of many different types of microorganisms. The propagules of pathogens which are affected by specific suppression do not tend to decline rapidly in soil. They are small (<200 μm in diameter), do not store large quantities of nutrients and rely on exogenous C sources such as seed and root exudates for germination and infection (Nelson, 1990). These pathogens are sensitive to the activities of other microorganisms in the soil, i.e. they are sensitive to microbiostasis. Examples of diseases suppressed in this "general" manner include *Phytophthora* and *Pythium* spp. (Hoitink *et al*., 1997).

Specific disease suppression occurs where the presence of just one or two microorganisms can explain suppression of a particular pathogen or the disease that it causes. It has been suggested that the specific microorganism or microorganisms responsible for this effect can be transferred from one soil to another in order to confer suppressivity, whereas those responsible for general suppression cannot as easily (Baker and Cook, 1974). Examples of pathogens suppressed in this way include *Rhizoctonia solani* and *Sclerotium rolfsii*. These pathogens both produce large propagules known as sclerotia which do not rely on exogenous C sources for germination and infection. During suppression, the sclerotia are colonised by specific hyperparasites (mainly *Trichoderma* spp.) and their inoculum potential is reduced. Microorganisms that produce antibiotics and those that induce systemic resistance in plants (to specific pathogens) represent other examples of specific suppression.

The main factors known to affect the degree of disease suppression conferred by composts are discussed in more detail below.

4.6.5.1 Feedstock type, composting system and compost maturity level

Composts made from a wide variety of feedstocks have been used with success to prevent and control pathogens. In most cases, the feedstocks have been chosen due to their low cost and/or ease of procurement in the geographical area in question. However several workers have shown that composts made using similar methods but from different feedstocks may perform differently. For example de Brito Alvarez *et al.* (1995) found that three out of four composts prepared from different feedstocks were associated with improved growth of tomato, whereas the fourth compost significantly depressed tomato plant growth. Aryantha *et al*., (2000) showed that fresh chicken manure or chicken manure composted for 5 weeks suppressed root rot caused by *Phytophthora cinnamomi*. They also found that chicken manure composted for 2 weeks was less suppressive and that composts made from cow, sheep or horse manure did not suppress root rot caused by *Phytophthora cinnamomi*. Several consultants and researchers (mainly in the United States) are now suggesting that it is possible to "tailor make" composts for particular crops, soils and host/pathogen combinations (www.soilfoodweb.com). The work to support these recommendations is not yet widely published in the scientific literature and further work is required to fully develop these theories into practice for UK crops and soils.

Most composts which have been used successfully to prevent and control diseases have been produced aerobically. Even composts produced aerobically contain small pockets of anaerobic material. However, it is recognised that composts produced under predominantly anaerobic conditions contain a range of toxic end products including low molecular weight organic acids. Some of these composts can remain toxic to plants for months or years (Hoitink, 1980). The presence of these toxic products is less critical for composts used in field soil if incorporation occurs well ahead of planting.

The maturity level of a compost is crucial in determining its disease suppressiveness. Fresh organic matter does not support biocontrol, even if it is inoculated with microbial species/strains of proven efficacy (De Ceuster *et al.*, 1999). High concentrations of free nutrients in fresh crop residues inhibit the production of enzymes required for parasitism by biocontrol agents such as *Trichoderma* spp.. Composts must be sufficiently stable and colonised to a degree that allows microbiostasis to prevail. Immature composts also frequently contain toxic compounds which affect the growth of crop plants and pre-dispose them to attack by pests and pathogens. On the other hand, excessivly humified organic matter, such as dark sphagnum peat, cannot support the activity of biocontrol agents. Composts which contains organic matter with properties in between the two extremes of decomposition is likely to best support biocontrol. There are several diagnostic tests available to determine compost maturity, and further tests are currently being developed.

4.6.5.2 Chemical and physical attributes of the compost

Several chemical and physical compost properties are known to affect crop growth and health and the degree of compost suppressiveness. These include: cellulose and lignin content, electrical conductivity (content of soluble salts), pH, the presence of toxic compounds, N content, particle size and air-filled porosity (especially in container media).

The principal chemical properties that affect biological control in composts identified so far include the presence of toxic compounds, the available C:N ratio, the concentration of soluble salts and possibly also the chloride ion concentration (Hoitink *et al.*, 1993). Composts based on tree bark release toxic compounds (natural fungicides) that lyse zoospores and sporangia of *Phytophthora* spp. As the decomposition level of composts increases, the role of these natural fungicides in the overall suppressive effect on the pathogen decreases and the contribution of the biocontrol agents gradually increases.

The total salt content in composts has been shown to affect the biological control of root rot caused by *Phytophthora* spp. on soybean (Hoitink *et al.*, 1993). Composted municipal solid waste applied 4 months ahead of planting (to allow for leaching of salts) increased soybean yield and controlled the root rot. Application of the same compost just prior to planting decreased soybean yield in comparison to the control. The amount of N present in composts has also been shown to affect disease suppressivity. Phytophthora dieback and fireblight (caused by *Erwinia amylovora*) are two examples of diseases which are increased as a result of excessive N fertility (Hoitink *et al*., 1986). Fusarium diseases tend to be increased by compost amendments which are high in ammonium N in particular. This means that they can be enhanced in field soils or container media amended with sewage sludge composts. Sewage sludge composts have a low C:N ratio and release predominantly ammonium N (Kato *et al*., 1981). Addition of hardwood tree bark (which immobilises N) to substrates amended with high N sewage sludge has been shown to confer disease suppression.

4.6.5.3 Fate of plant pathogens and biocontrol agents during composting

Disease suppressive composts should by definition contain no plant pathogens. Eradication of plant pathogens present in the original feedstock occurs during the composting process as a result of exposure to high temperatures, release of toxic products during or after the self-heating process and microbial antagonism in the sub-lethal outer temperature zones of piles/windrows or later during curing. Most plant pathogens are killed by 30 minutes exposure to 55^{o}C (Hoitink and Fahy, 1986). A few plant pathogens such as the tobacco mosaic virus, the clubroot pathogen (*Plasmodiophora brassicae*) and some *forma speciales* of *Fusarium oxysporum* are less sensitive to heat and highly controlled in-vessel composting systems may be required if feedstock material is likely to be contaminated with such pathogens.

Most beneficial microorganisms are also killed during the high temperature phase of composting, however, some remain in the outer low temperature parts of the compost pile/windrow (Hoitink *et al*., 1997). The disease suppressive properties of composts are usually induced during curing, because most biocontrol agents recolonise the compost after peak heating. A wide range of microorganism species has been identified as biocontrol agents in compost-amended substrates. These include *Bacillus* spp., *Enterobacter* spp., *Flavobacterium balustinum* 299, *Pseudomonas* spp., other bacterial genera and *Streptomyces* spp. as well as fungal species including *Penicillium* spp, *Gliocladium virens*, several *Trichoderma* spp. and others (Chung and Hoitink, 1990; Hoitink *et al*., 1997). Compost moisture content (ideally 40-50% moisture) is critical if the compost is to be successfully colonised by disease suppressive microorganisms after peak heating.

Compost produced in the open, in an environment which is high in microbial species diversity has been shown to be colonised by a greater variety of microbial species than the same produced in an in-vessel system (Kuter *et al*., 1983). This may be partly because the survival of a wide range of beneficial microorganism species is less likely in in-vessel systems, because the entire contents of the vessel will reach consistently high temperatures at the same time. Composts made in enclosed systems may require to be cured for longer to improve suppressiveness, incorporated into soils for several months prior to planting or they may require inoculation with specific biological control agents (Hoitink *et al*., 1997).

4.6.5.4 Biological attributes of the compost
Very little information exists on the biology of compost-amended soils. A significant amount of literature now exists on biocontrol agents in container media however, and much of this can be studied with a view to extending the work into field soils in the future.

4.6.5.4.1 Microflora and fauna associated with suppressive composts
There is an increasing body of information on the antagonists involved in suppression of plant pathogens in compost-amended media. The types of microorganisms isolated are similar to those studied by scientists working on biological control in field soils.

It has been demonstrated that fungal populations in composted hardwood bark media suppressive and conducive to rhizoctonia damping-off differ significantly (Kuter *et al*., 1983). Although no single species dominated in all the media tested, *Trichoderma* and *Gliocladium virens* were abundant in all suppressive media. *Trichoderma* spp. were also identified as important fungal antagonists in composts prepared from larch bark for control of fusarium brown rot in chinese yam (Sekiguchi, 1977).

There is little information available on the activity of bacterial antagonists in composts or compost-amended soils. Bacterial antagonists recovered at random by baiting with propagules of *Rhizoctonia solani* or plant roots from suppressive batches of composted hardwood bark include isolates of *Pseudomonas aeruginosa, P. putida, P. stutzeri, Xanthomonas maltophilia, Janthinobacterium lividum, Flavobacterium balustinum, Enterobacter cloacae, E. agglomerans, Bacillus cereus, B. mycoides* and *B. subtilis*. It is not known which of these bacterial antagonists predominate in suppressive composts or what their relative contributions are. However it can be concluded that the bacterial and fungal colonists isolated are rapid, primary colonisers of organic matter.

Microarthropods (springtails and mites) play a role in the suppression of soilborne plant pathogens in compost-amended substrates, although specific reports on their role in composts are few. It is known that they are most active in soils which contain high levels of organic matter.

4.6.5.4.2 Specific antagonist-amended composts
Composts made from hardwood bark and municipal sludge can be made predictably suppressive to damping-off caused by both *Rhizoctonia* and *Pythium* spp. by amendments with specific antagonists. (Hoitink and Fahy, 1986). The composts produced are 2.5 - 3.2 fold as suppressive as the unamended, naturally suppressive compost. The increased activity of composts such as this means that reduced application rates are required and input

costs are lower. Work is now going on (mainly in the United States) to develop a range of purpose-designed composts for use in specific soil/crop/climate combinations.

4.6.5.5 Mode of action of compost teas

Compost teas sprayed on to plant leaves act in the phyllosphere (i.e. the leaf surface). The principal active agents in compost teas appear to be bacteria in the genera *Bacillus, Serratia, Penicillium* and *Trichoderma*, although other genera are involved (Brinton *et al*., 1996). There is no single mechanism which explains the effects of compost extracts against foliar plant pathogens. It is possible to divide the effects of compost extracts into three categories:

- inhibition of spore germination
- antagonism and competition with pathogens
- induced resistance against pathogens

The main effects of compost extracts appear to be associated with live microorganisms. Sterilised or micron filtered compost extracts have usually been shown to have significantly reduced activity against test pathogens (Weltzein and Ketterer, 1986). In a few cases, sterilised extracts have been shown to have limited activity against foliar pathogens. For example some chemicals produced by *Pseudomonas* spp. (e.g. siderophores) exert a powerful chemical effect against other organisms (Potera, 1994). Antiobiotics have been shown to be produced by *Bacillus subtilis* and these inhibit the growth and germination of many fungal species.

The phenomenon of induced or acquired systemic resistance may also explain part of the mode of action of some compost extracts and teas. There is plenty of evidence to show that microorganisms (whether pathogenic or not) can induce plant defence responses. For example, when cucumber leaves are inoculated with the fungus *Colletotrichum lagenarium*, the infected leaves become resistant not only to attack by *C. lagenarium*, but also towards all other foliar pathogens (Brinton *et al*., 1996). Knowledge of this phenomenon and its potential for control of plant pathogens is limited at this time.

4.6.5.5.1 Factors affecting efficacy of compost teas

There is sufficient information to show that in some cases, plant pathogen control has been at least as good with compost teas as with conventional fungicides (Ketterer, 1990). However, research also suggests that different preparation methods and different composts may be required in order to optimise the qualities of the final product and the application method. Table 4b summarises the main parameters which could influence efficacy of the finished compost extract or tea.

4.7 Conclusions and recommendations for future work

There is mounting pressure on UK organic farmers to increase both crop yield and quality in order that they can maintain and improve their place in the European marketplace. There is increasing evidence that the use of uncomposted plant residues, composts, manures and compost extracts/teas can help them do this through improvements in soil quality and health and through direct and indirect control of pests and diseases.

In a few documented cases, control of named pests or diseases using composts or compost extracts/teas in conventional systems has been equal to or better than that achieved with synthetic pesticides. However, for many pests and diseases, the level of control which has

Table 4b Parameters which may influence quality of compost extracts and teas

Fermentation parameter

Production system component	Critical points
Fermentation vessel	dimensions, manufacturer, model
Compost	feedstocks, age, stability, % moisture, microbial analysis, volume/bulk density or weight
Water source	volume, initial temperature, final temperature
Fermentation nutrients	source, quantity and application time
Oxygen content	depends on amount, frequencey and nature of agitation/aeration/stirring
Fermentation duration	method and time of storage if not used immediately

Application parameter

Production system component	Critical points
Filtration	nature of filter
Dilution ratio	water source used
Adjuvants	type (e.g. spreaders, stickers, wetters, UV stabilisers, nutrients and microorganisms)
Application equipment	make, model, nozzle type, PSI during application
Application	dose rate, time of day, weather, spray interval

been demonstrated in glasshouse and field trials would be considered inadequate for conventional growers. For organic growers, who have no access to synthetic fungicides, the use of organic amendments may provide a useful addition to the range of partial disease control solutions to which they have access.

Considerable work is required to ensure predictable disease suppression and control from organic residues including composts and compost teas for different crops in different climates and soils. Much of the current work has been done, or is being done in the United States on different crops and in very different climates, soils and farming systems from those in the UK. It will be necessary to develop the techniques and protocols successfully developed in other countries for use in UK organic farming systems.

A great deal of the recent work on composts has been carried out using feedstocks which are not readily available in the UK. Research is required to assess the quality and disease suppressive properties of composts made from feedstocks which are cheap and readily available to UK farmers.

Work relating to compost teas is still in the early stages, although consultants and farmers (both conventional and organic) in the United States are claiming some degree of disease control when using them. Work is required to identify the key active microorganisms in compost teas/extracts and to develop production processes to ensure that they exist in appropriate numbers. Application technology, which has been developed mainly to ensure optimal application of pesticides must be adapted for use with compost teas. An improved understanding of the mode(s) of action of compost teas may also allow the combination of other natural products and biological agents to treat organic crops. Work on compost teas is continuing rapidly in the United States. Much of the information relating to current preparation and application methods for compost extracts/teas is available free on the internet. Again however, considerable work is required to develop and adapt the techniques currently used in the United States for use on UK organic crops.

4.8 References

Abawi, G.S. and Crosier, D.C. (1992) Influence of reduced tillage practices on root-rot severity and yield of snap beans, 1991*. American Phytopathological Society, Biological and cultural tests* 7, 9.

Abawi, G.S. and Widmer, T.L. (2000) Impact of soil health management practices on soilborne pathogens, nematodes and root diseases of vegetable crops*. Applied Soil Ecology* 15, 37-47.

Abdel-Fattah, G.M. and Mohamedin, A.H. (2000) Interactions between a vesicular-arbuscular mycorrhizal fungus (*Glomus intraradices*) and *Streptomyces coelicolor* and their effects on sorghum plants grown in soil amended with chitin of brawn scales. *Biology and Fertility of Soils* 32, 401-409.

Adewusi, S.R.A. (1990) Turnover of dhurrin in green sorghum seedlings. *Plant Physiology* 94, 1219.

Akhtar, M. (1999) Plant growth and nematode dynamics in response to soil amendments with neem products, urea and compost. *Bioresource Technology* 69, 181-183.

Akhtar, M. and Malik, A. (2000) Roles of organic soil amendments and soil organisms in the biological control of plant-parasitic nematodes - a review. *Bioresource Technology* 24, 35-47.

Armstrong, G. and McKinlay, R.G. (1997). The effect of undersowing cabbages with clover on the activity of carabid beetles. *Biological Agriculture and Horticulture* 15, 269-277.

Arnold, P.T. and Kapustka, L.A. (1987) VA mycorrhizal colonisation and spore populations in an abandoned agricultural field after five years of sludge application. *Ohio Journal of Science* 87, 112-114.

Aryantha, I.P., Cross, R. and Guest, D.I. (2000) Suppression of *Phytophthora cinnamomi* in potting mixes amended with uncomposted and composted animal manures. *Phytopathology* 90, 775-782.

Baby, U.I. and Manibhushanrao, K. (1996) Influence of organic amendments on arbuscular mycorrhizal fungi in relation to rice sheath blight disease. *Mycorrhiza* 6, 201-206.

Baker, K.F. and Cook, R.J. (1974) Biological control of plant pathogens. In: A. Kelman and L. Sequira (eds.) The Biology of Plant Pathogens. W.H. Freeman and Co., San Francisco, USA.

Baltruschat, H. and Dehne, H.W. (1988) The occurrence of vesicular-arbuscular mycorrhiza in agro-ecosystems. *Plant and Soil* 107, 279-284.

Beare, M.H., Coleman, D.C., Crossley, D.A., Hendix, P.F. and Odum, E.P. (1995). A hierarchical approach to evaluating the significance of soil biodiversity to biogeochemical cycling. In: H.P. Collins, G.P. Robertson and M.J. Klug (eds.) *The significance and regulation of soil biodiversity*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Bending, G.D., Turner, M.K., Jones, J.E. (2002) Interactions between crop residue and soil organic matter quality and the functional diversity of soil microbial communities. *Soil Biology & Biochemistry* 34, 1073-1082.

Benítez, E., Melgar, R., Sainz, H., Gómez, M. and Nogales, R. (2000) Enzyme activities in the rhizosphere of pepper (*Capsicum annuum* L.) grown wih olive cake mulshes. *Soil Biology and Biochemistry* 32, 1829-1835.

Boehm, M.J. and Hoitink, H.A.J. (1992) Sustenance of microbial activity in potting mixes and its impact on severity of pythium root-rot of poinsettia. *Phytopathology* 82, 259-263.

Bongers, T. and Ferris, H. (1999) Nematode community structure as a bioindicator in environmental monitoring. *Trends in Ecology and Evolution* 14, 224-228.

Boogert, P.H.G.F., van den, Velvis, H., Ettema, C.H. and Bouwman, L.A. (1994) The role of organic matter in the population dynamics of the endoparasitic nematophagous fungus *Drechmeria coniospora* in microcosms. *Nematologica* 40, 249-257.

Bouwman, L.A. and Zwart, K.B. (1994) The ecology of bacterivorous protozoans and nematodes in arable soil. *Agricultural Ecosystems and Environment* 51, 145-160.

Boyle, M. and Paul, E.A. (1988) Vesicular –arbuscular mycorrhizal associations with barley on sewage-amended plots. *Soil Biology and Biochemistry* 20, 945-948.

Brinton, W.F., Tränkner, A. and Droffner, M. (1996) Investigations into liquid compost extracts. *Biocycle* 37 (11), 68-70.

Brown, G.G. (1995) How do earthworms affect microfloral and faunal community and diversity. *Plant and Soil* 170, 209-231.

Bulluck, L.R., Barker, K.R. and Ristaino, J.B. (2002) Influences or organic and synthetic soil fertility amendments on nematode trophic groups and community dynamics under tomato. *Applied Soil Ecology* 21, 233-250.

Bulluck, L.R., Brosius, M., Evanylo, G.K. and Ristaino, J.B. (2002) Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms *Applied Soil Ecology* 19, 147-160.

Bulluck, L.R. and Ristaino, J.B. (2002) Effect of synthetic and organic soil fetility amendments on Southern blight, soil microbial communities and yield of processing tomatoes. *Phytopathology* 92, 181-189.

Caravaca, F., García, C., Hernandez, T. and Roldán, A (2002) Aggregate stability changes after organic amendment and mycorrhizal inoculation in the afforestation of a semiarid site with Pinus halepensis. *Applied Soil Ecology* 19, 199-208.

Chen, J., Abawi, G.S. and Zuckerman, B.M. (2000) Efficacy of *Bacillus thuringiensis, Paecilomyces marquandii* and *Streptomyces constaricanus* with and without organic amendment against *Meloidogyne hapla* infecting lettuce. *Journal of Nematology* 32, 70-77.

Chung, Y.R. and Hoitink, H.A.J. (1990) Interactions between thermophilic fungi and *Trichoderma hamatum* in suppression of rhizoctonia damping-off in a bark compost-amended container medium. *Phytopathology* 80, 73-77.

Cooke, R.C. (1962) Behaviour of nematode trapping fungi during decomposition of organic matter in the soil. *Transactions of the British Mycological Society* 45, 314-320.

Cook, R.J. and Baker, K.F. (1983*) The nature and practice of biological control of plant pathogens*. American Phytopathological Society, St. Paul, Minnesota.

Cooke, D. A. (1993) Pests. In: D A Cooke and R K Scott (eds.) *The sugar beet crop*, London, Chapman and Hall, pp 429-484.

Cooper, J.M. and Warman, P.R. (1997) Effects of three fertility amendments on soil dehydrogenase activity, organic C and pH. *Canadian Journal of Soil Science* 77, 281-283.

Cousin, C., Grant, J., Dixon, F., Beyene, D. and Van Berkum, P. (2002) Influence of bioosolids compost on the *Bradyrhizobial* genotypes recovered form cowpea and soybean nodules. *Archives of Microbiology* 177, 427-430.

Cronin, M.J., Yohalem, D.S., Harris, R.F. and Andrews, J.H. (1996) Putative mechanism and dynamics of inhibition of the apple scab pathogen *Venturia inaequalis* by compost extracts. *Soil Biology and Biochemistry* 28, 1241-1249.

Dackman, C., Olssen, S., Jansson, H,B., Lundgren, B. and Nordbring-Hertz, B. (1987) Quantification of predatory and endoparasitic nematophagous fungi in soil. *Microbiological Ecology* 13, 89-93.

de Brito Alvarez, M.A., Gagné, S. and Antoun, H. (1995) Effect of compost on rhizosphere microflora of the tomato and on the incidence of plant growth promoting Rhizobacteria. *Applied and Environmental Microbiology* 61, 194-199.

de Caire, G.Z., de Cano, M.S., Palma, R.M. and de Mulé, C.Z. (2000) Changes in soil enzyme activities following additions of cyanobacterial biomass and exopolysaccharide. *Soil Biology and Biochemistry* 32, 1985-1987.

De Ceuster, T.J.J. and Hoitink, H.A.J. (1999) Prospects for composts and biocontrol agents as substitutes for methyl bromide in biological control of plant diseases. *Compost Science and Utilization* 7, 6-15.

D'Errico, F.P. and Di Maio, F. (1980) Effets des boues résiduaires compostées sur la culture et le développement de la pedofaune associée a l'oeillet. *Revue Zoologie Agriculture* 79, 23-28.

Díaz-Raviña, M., Prieto, A. and Bååth, E. (1996) Bacterial activity in a forest soil after soil heating and organic amendments measured by the thymidine and leucine incorporation techniques. *Soil Biology and Biochemistry* 28, 419-426.

Dick, R.P. (1992) A review, longterm effects of agricultural systems on soil biochemical and microbial parameters. *Agriculture, Ecosystems and Environment* 40, 25-36.

Ditzler, C.A. and Tugel, A.J. (2002) Soil quality field tools: Experiences of USDA-NRCS Soil Quality Institute. *Agronomy Journal* 94, 33-38.

Diver, S. (2001) Notes on compost teas: a 2001 supplement to the ATTRA publication "Compost teas for plant disease control". ATTRA publication, Fayetteville, Arkansas.

Douds, D.D., Galvez, L., Franke-Snyder, M., Reider, C. and Drinkwater, L.E. (1997) Effect of compost addition and crop rotation point upon VAM fungi. *Agricultural Ecosystems and the Environment* 65, 257-266.

Duponnois, R., Chotte, J.L., Sall, S. and Cadet, P. (2001) The effects of organic amendments on the interactions between a nematophagous fungus *Arthrobotrys oligospora* and the root knot nematode *Meloidogyne mayaguensis* parasitizing tomato plants. *Biology and Fertility of Soils* 34, 1-6.

Ferraz, L.C.L., Café Filho, A.C., Nasser, L.C.B. and Azevedo, J. (1999) Effects of soil moisture, organic matter and grass mulching on the carpogenic germination of sclerotia and infection of bean by *Sclerotinia sclerotiorum*. *Plant pathology* 48, 77-82.

Frostegård, A., Petersen, S.O., Bååth, E. and Nielsen,T.H. (1997) Dynamics of a microbial community associated with manure hot spots as revealed by phospholipid fatty acid analysis. *Applied and Environmental Microbiology* 63, 2224-2231.

García, C., Hernandez, T., Roldán, A., Albaladejo, J. and Castillo, V. (2000) Organic amendment and mycorrhizal inoculation as a practice in afforestation of soils with *Pinus halepensis* Miller, effect on their microbial activity. *Soil Biology and Biochemistry* 32, 1173-1181.

García, C., Hernandez, T. and Costa, F. (1997) Potential use of dehydrogenase activity as an index of microbial activity in degraded soils*. Communication in Soil Science and Plant Analysis* 28, 123-134.

García, C., Hernandez, T., Albaladejo, J., Castillo, V. and Roldán, A. (1998) Revegetation in semiarid zones, Influence of terracing and organic refuse on microbial activity. *Soil Science Society of America Journal* 62, 670-678.

García-Gil, J.C., Plaza, C., Soler-Rovira, P. and Polo, A. (2000) Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. *Soil Biology and Biochemistry* 32, 1907-1913.

Gaur, A. and Adholeya, A. (2000) On farm production of VAM inoculum and vegetable crops in marginal soil amended with organic matter*. Tropical Agriculture* 77, 21-26.

Giller, K.E., McGrath, S.P. and Hirsch, D.R. (1988) Absence of nitrogen fixation in clover grown on soil subject to long term contamination with heavy metals is due to survival of only effective *Rhizobium*. *Soil Biology and Biochemistry* 21, 841-848.

Gonzalez, A. and Canto Sanenz, M. (1993) Comparison of five organic amendments for the control of *Globodera pallida* in microplots in Peru. *Nematropica* 23, 133-139.

Gorodecki, B. and Hadar, Y. (1990) Suppression of *Rhizoctonia solani* and *Sclerotium rolfsii* in container media containing composted separated cattle manure and composted grape marc. *Crop Protection* 9, 271-274.

Hadar, Y. and Mandelbaum, R. (1986) Suppression of *Pythium aphanidermatum* damping-off in container media containing composted liquorice roots. *Crop Protection* 5, 88-92.

Hafner, H., George, E., Bationo, A. and Marschner, H. (1993) Effect of crop resuidues on root growth and phosphorus acquisition of pearl millet in an acid sandy soil in Niger. *Plant and Soil* 150, 117-127.

Harinikumar, K.M. and Bagyaraj, D.J. (1988) Effect of crop rotation on native vesicular-arbuscular mycorrhizal propagules in soil. *Plant and Soil* 110, 77-80.

Harinikumar, K.M. and Bagyaraj, D.J. (1989) Effect of cropping sequence, fertilisers and farmyard manure on vesicular-arbuscular mycorrhizal fungi in different crops over three consecutive seasons. *Biology and Fertility of Soils* 7, 173-175.

He, Z.L., Alva, A.K., Calvert, D.V., Li, Y.C., Stofella, P.J. and Banks, D.J. (2000) Nutrient availibility and changes in microbial biomass of organic amendments during field incubation. *Compost Science and Utilisation* 8, 293-302.

Heckman, J.R. and Kluchinski, D. (1995) Soybean nodulation and nitrogen fixation on soil amended with plant residues. *Biology and Fertility of Soils* 20, 284-288.

Hegazi, N.A., Khawas, H.M. and Monib, M. (1986) Effect of incorporation of crop residues on development of diazotrophs and patterns of acetylene-reducing activity in Nile Valley soils. *Plant and Soil* 90, 383-389.

Höflich, G. and Metz, R. (1997) Interactions of plant-microorganism-associations in heavy metal containing soils from sewage farms. *Die Bodenkultur* 48, 239-247.

Hoitink, H.A.J. (1980) Composted bark, a lightweight growth medium with fungicidal properties. *Plant Disease* 64, 142-147.

Hoitink, H.A.J. and Fahy, P.C. (1986) Basis for the control of soilborne plant pathogens with composts. *Annual Review of Phytopathology* 24, 93-114.

Hoitink, H.A.J., Boehm, M.J. and Hadar, Y. (1993) Mechanisms of suppression of soilborne plant pathogens in compost-amended substrates. In: H.A.J. Hoitink and H.M.Keener (eds.) *Science and engineering of composting: Design, environmental, microbiological and utilisation aspects*. Renaissance publications, Worthington, Ohio, USA.

Hoitink, H.A.J., Stone, A.G. and Han, D.Y. (1997) Suppression of plant disease by composts. *Hortscience* 32, 184-187.

Hoitink, H.A.J., Watson, M.E. and Faber, W.R. (1986) Effect of nitrogen concentration in juvenile foliage of rhododendron on phytophthora dieback severity. *Plant Disease* 70, 292-294.

Hornby, D. (1990) *Biological control of soilborne plant pathogens*. CAB International, Wallingford, UK.

Huebner, R.A., Rodríguez-Kábana, R. and Patterson, R.M. (1983) Hemi-cellulosic waste and urea for control of plant-parasitic nematodes: Effect on soil enzyme activities. *Nematropica* 13, 37-54.

Hunt, P.G., Hortenstine, C.C. and Smart, G.C. (1973) Responses of plant parasitic and saprophytic nematode populations to composted municipal refuse. J*ournal of Environmental Quality* 2, 264-266.

Ibekwe, A.M., Papiernik, S.K., Gan, J., Yates, S.R., Crowley, D.E. and Yang, C.H. (2001) Microcosm enrichment of 1,3-dichloropropene-degrading soil microbial communities in a compost-amended soil. *Journal of Applied Microbiology* 91, 668-676.

Ingham, E.R. (1999) Making a high quality compost tea, Part II, *Biocycle* 40 (4), 94

Ingham, E.R. (2000) *The compost tea brewing manual.* Unisun Communications, Corvallis, Oregon, USA.

Ingham, E.R. and Alms, M. (1999) *Compost tea manual.* Soil Food Web Inc., Corvallis, Oregon, USA.

Ishac, Y.Z., El-Haddad, M.E., Daft, M.J., Ramadan, E.M. and El-Demerdash, M.E. (1986) Effect of seed inoculation, mycorrhizal infection and organic amendment on wheat growth. *Plant and Soil* 90, 373-382.

Jacquot, E., van Tuinen, D., Gianinazzi, S. and Gianinazzi-Pearson, V. (2000) Monitoring species of arbuscular mycorrhizal fungi *in planta* and in soil by nested PCR: application to the study of the impact of sewage sludge. *Plant and Soil* 226, 179-188.

Jacquot-Plumey, E., van Tuinen, D., Chatagnier, O., Gianinazzi, S. and Gianinazzi-Pearson, V. (2001) 25S rDNA-based molecular monitoring of glomalean fungi in sewage sludge-treated field plots. *Environmental Microbiology* 3, 525-531.

Jaffee, B.A. (2002) Soil cages for studying how organic amendments affect nematode trapping fungi. *Applied Soil Ecology*, In Press.

Jaffee, B.A., Ferris, H. and Scow, K.M. (1998) Nematode trapping fungi in organic and conventional cropping systems. *Phytopathology* 88, 344-350.

Jaffee, B.A., Ferris, H., Stapleton, J.J., Norton, M.V.K. and Muldoon, A.E. (1994). Parasitism of nematodes by the fungus *Hirsutella rhossiliensis* as affected by certain organis amendments. *Journal of Nematology* 26, 152-161.

Joner, E.J. (1995) The effect of long-term fertilization with organic or inorganic fertilizers on mycorrhiza mediated phosphorus uptake in subterranean clover*. Biology and Fertility of Soils* 32, 435-440.

Kahindhi, J.H.P., Woomer, P., George, T., Moreira, F.M.D., Karanja, N.K. and Giller, K.E. (1997). Agricultural intensification, soil biodiversity and ecosystem function in the tropics: the role of nitrogen-fixing bacteria. *Applied Soil Ecology* 6, 55-76.

Kato, K., Fukaya, M. and Tomita, I. (1981) Effect of successive applications of various soil amendments on tomato fusarium wilt*. Research Bulletin of the Aichi Agricultural Research Centre* 13, 199-208.

Keeling, A.A. and Cook, J.A. (1999) Estimate of N_2-fixation in waste derived compost after treatment with glucose. *European Journal of Soil Biology* 34, 151-155.

Ketterer, N. (1990) Untersuchungen zur Wirkung von kompost-extracten auf den Blattbefall ser kartoffel und tomate durch *Phytophthora infestans* sowie auf den befall der weinrebe durch *Plasmopara viticola, Pseudopeziza tracheiphila* und *Uncinula necator*. Dissertation, University of Bonn.

Kim, K.D., Nemec, S. and Musson, G. (1997) Control of Phytophthora root and crown rot of bell pepper with composts and soil amendments in the greenhouse. *Applied Soil Ecology* 5, 169-179.

Kokalis-Burelle, N., Rodríguez-Kábana, R.; Weaver, C.F. and King, P.S. (1994) Evaluation of powdered pine bark for control of *Meloidogyne arenaria* and *Heterodera glycines* on soybean. *Plant and Soil* 162, 163-168.

Kokalis-Burelle, N. and Rodríguez-Kábana, R. (1994) Changes in populations of soil microorganisms, nematodes and enzyme activity associated with application of powdered pine bark. *Plant and Soil* 162, 169-175.

Kooman, I., McGrath, P. and Giller, K.E. (1990) Mycorrhizal infection of clover is delayed in soils contaminated with heavy metals from past sewage sludge applications. *Soil Biology and Biochemistry* 22, 871-873.

Kuter, G.A., Hoitink, H.A.J. and Chen, W. (1988) Effects of municipal sludge compost curing time on suppression of pythium and rhizoctonia diseases of ornamental plants. *Plant Disease* 72, 751-756.

Kuter, G.A., Nelson, E.B., Hoitink, H.A.J. and Madden, L.V. (1983) Fungal populations in container media amended with composted hardwood bark suppressive and conducive to rhizoctonia damping-off. *Phytopathology* 73, 1450-1456.

Lampkin, N. (1990). *Organic Farming*. Farming Press Books, Ipswich, UK.

Leporini, C., Pera, A., Vallini, G., Picci, G. and Giovannetti, M. (1992) Influence of MSW derived compost on *Rhizobium trifolii* and the VA mycorrrhzal endophyte *Glomus mosseae* in a low fertility soil. *Acta Horticulturae* 302, 385-390.

Lima, J.A., Nahas, E. and Gomes, A.C. (1996) Microbial populations and activities in sewage sludge and phosphate fertiliser amended soil. *Applied Soil Ecology* 4, 75-82.

Lewis, J.A., Lumsden, R.D., Millner, P.D. and Keinath, A.P. (1992) Suppression of damping-off of peas and cotton in the field with composted sewage sludge. *Crop Protection* 11, 260-265.

Litterick, A.M., Watson, C.A. and Atkinson, D. (2002) Crop protection in organic agriculture - a simple matter? *Proceedings of the Crop Protection in Northern Britain Conference* 2002, pp. 19-26.

Lodha, S. and Burman, U. (2000) Efficacy of composts on nitrogen fixation, dry root-rot (*Macrophomina phaseolina*) intensity and yield of legumes. *Indian Journal of Agricultural Sciences* 70, 846-849.

Lopez-Llorca, L.V. and Olivares-Bernabeu, C. (1997) Growth inhibition of nematophagous and entomopathogenic fungi by leaf litter and soil containing phenols. *Mycological Research* 101, 691-697.

Loth, FG. (1996) Abundance of arbuscular mycorrhizal fungi spores at different native sites in dependence on sewage sludge applications. *Die Bodenkultur* 47, 89-96.

Loth, FG. and Höfner, W. (1995) Einfluss von klärschlammbehandelten Böden auf die infektiosität von VA-mykorrhiza-pilzisolaten bei verschiedenen kulturpflazen*. Agribiological Research* 48, 269-281.

Ma, L.P., Qiao, X.W., Gao, F. and Hao, B.Q. (2001) Control of sweet pepper fusarium wilt with compost extracts and its mechanism. *Chinese Journal of Applied and Environmental Biology* 7, 84-87.

Madariaga, G.M. and Angle, J.S. (1992) Sludge borne salt effects on the survival of *Bradyrhizobium japonicum. Journal of Environmental Quality* 21, 276-280.

Mader, P., Edenhofer, S., Boller, T., Wiemken, A. and Niggli, U. (2000) Arbuscular mycorrhizae in a long term field trial comparing low input (organic, biological) and high input (conventional) farming systems. *Biology and Fertility of Soils* 31, 150-156.

Marull, J., Pinochet, J. and Rodrigues-Kabana, R. (1997) Agricultural and municipal compost residues for control of root-knot nematodes in tomato and pepper*. Compost Science and Utilisation* 5, 6-15.

McGrath, S.P., Brookes, P.C. and Giller, K.E. (1988) Effect of potentially toxic metals in soil derived from past applications of sewage sludge on nitrogen fixation by *Trifolium repens* L. *Soil Biology and Biochemistry* 20, 415-424.

McSorley, R. and Frederick, J.J. (1999) Nematode population fluctuations during decomposition of specific organic amendments. *Journal of Nematology* 31, 37-44.

McSorley, R. and Gallaher, R.N. (1995a) Cultural practices improve crop tolerance to nematodes. *Nematropica* 25, 53-59.

McSorley, R. and Gallaher, R.N. (1995b) Effect of yard waste compost on plant-parasitic nematode densities in vegetable crops. *Journal of Nematology* 27, 545-549.

McSorley, R. and Gallaher, R.N. (1996) Effect of yard waste compost on nematode densities and maize yield. Journal of Nematology 28, 655-660.

McSorley, R. and Gallaher, R.N. (1997) Effect of compost and maize cultivars on plant-parasitic nematodes. *Supplement to the Journal of Nematology* 29, 731-736.

Mendum, T.A. and Hirsch, P.R. (2002) Changes in the population structure of [ß]-group autotrophic ammonia oxidising bacteria in arable soils in response to agricultural practice. *Soil Biology and Biochemistry* 34, 1479-1785.

Mian, I.H. and Rodríguez-Kábana, R. (1982) Chitin amendments for control of *Meloidogyne arenaria* in infested soil. *Nematropica* 12, 71-84.

Mills, D.J., Coffman, C.B. and Teasdale, J.R. (2002) Factors associated with foliar disease of staked fresh tomatoes grown under differing bed strategies. *Plant Disease* 86, 356-361.

Miyashita,K., Kato, T. and Tsuru, S. (1982) Actinomycetes occurring in soil applied with compost. *Soil Science and Plant Nutrition* 28, 303-318.

Mojtahedi, H., Santo, G.S. and Ingham, R.E. (1993) Suppression of *Meloidogyne chitwoodi* with sudangrass cultivars as green manure. *Journal of Nematology* 25, 303-311.

Mojtahedi, H.; Santo, G.S.; Hang, A.N. and Wilson, J.H. (1991) Suppression of root-knot nematode populations with selected rapeseed cultivars as green manure. Journal of *Nematology* 23, 170-174.

Muir, J.P. (2002) Hand plucked forage yield and quality and seed Production from annual and short lived perennial warm-season legumes fertilised with composted manure. *Crop Science* 42, 897-904.

Muthukumar, T. and Udaiyan, K. (2000) Influence of organic manure's on arbuscular mycorrhizal fungi associated with *Vigna unguiculata* (L.) Walp. In relation to tissue nutrients and soluable carbohydrate in roots under field conditions. *Biology and Fertility of Soils* 31, 114-120.

Muthukumar, T. and Udaiyan, K. (2002) Growth and Yield of cowpea as influenced by changes in arbuscular mycorrhiza in response to organic manuring. *Journal of Agronomy and Crop Science* 188, 123-132.

Nelson, E.B. (1990) Exudate molecules initiating fungal responses to seeds and roots. *Plant and Soil* 129, 61-73.

Nelson, E.B. and Craft, C.M. (1992) Suppression of dollar spot on creeping bentgrass and annual bluegrass turf with compost-amended topdressing. *Plant Disease* 76, 954-958.

Nelson, E.B., Kuter, G.A. and Hoitink, H.A.J. (1983) Effects of fungal antagonists and compost age on suppression of rhizoctonia damping-off in container media amended with composted hardwood bark. *Phytopathology* 73, 1457-1462.

Nickel, A., Pelz, O., Hahn, D., Saurer, M., Siegwolf, R. and Zeyer, J. (2001) Effect of inoculation and leaf litter amendment on establishment of nodule-forming *Frankia* populations in soil. *Applied and Environmental Microbiology* 67, 2603-2609.

Nicolay, R., Sikora, R.A. and Weltzien, H.C. (1990) Influence of green manure, straw and compost extracts on the activity of fungal egg parasites of *Heterodera schachtii* Schmidt. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz* 97, 470-483.

Noyd, R.K., Pfleger, F.L. and Norland, M.R. (1996) Field responses to added organic matter, arbuscular mycorrhizal fungi and fertiliser in reclamation of taconite iron ore tailing. *Plant and Soil* 179, 89-97.

Obbard, J.P., Sauerbeck, D.R. and Jones, K.C. (1993) *Rhizobium leguminosarum* bv. *trifolii* in soils amended with heavy metal contaminated sewage sludge. *Soil Biology and Biochemistry* 25, 227-231.

Ownley, B.H. and Benson, D.M. (1991) Relationship of matric water potential and air-filled porosity of container media to development of phytophthora root-rot of rhododendron. *Phytopathology* 81, 936-941.

Pandey, R. and Sikora, R.A. (2000) Influence of aqueous extracts of organic matter on the sensitivity of *Heterodera schachtii* Schmidt and *Meloidogyne incognita* (Kofoid and White) Chitwood eggs to *Verticillium chlamydosporium* Goddard infection. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz* 107, 494-497

Pascual, J.A., García, C., Hernandez, T., Moreno, J.L. and Ros,.M. (2000) Soil Microbial activity as a biomarker of degradation and remediation processes. *Soil Biology and Biochemistry* 32, 1877-1883.

Paul, J.W. and Beauchamp, E.G. (1996) Soil microbial biomass C, N mineralisation, and N uptake by corn in dairy cattle slurry and urea-amended soils. *Canadian Journal of Soil Science* 76, 469-472.

Pearson, J.N., Abbott, L.K., Jasper, D.A. (1994) Phosphorous soluble carbohydrates and the competition between two arbuscular mycorrhizal fungi colonising subterranean clover. *New Phytologist* 127, 101-106.

Porazinska, D.L., Duncan, L.W., McSoreley, R. and Graham, J.H. (1999). Nematode communities as indicators of status and processes of a soil ecosystem influenced by agricultural management practices. *Applied Soil Ecology* 13, 69-86.

Potera, C. (1994) From bacteria: a new weapon against fungal infection. *Science* 265, 605.

Pfiffner, L. and Mader, P. (1997) Effects of biodynamic, organic and conventional production systems on earthworm population. *Biological Agricuture and Horticulture* 15, 3-10.

Ramos, M.L.G. and Boddey, R.M. (1987) Yield and nodulation of *Phaseolus vulgaris* and the competitivity of an introduced *Rhizobium* strain: effects of lime mulch and repeated cropping. *Soil Biology and Biochemistry* 19, 171-177.

Riegel, C. and Noe, J.P. (2000) Chicken litter soil amendment effects on soilborne microbes and *Meloidogyne incognita* on cotton. *Phytopathology* 84, 1275-1281.

Riggle, D. (1996) Compost teas in agriculture. *Biocycle* 37 (12), 65-57.

Rodgers-Gray, B.S. and Shaw, M.W. (2001) The effect of incorporating straw or manure into the soil on the natural microflora of winter wheat. *Plant Pathology* 50, 537-545.

Rodríguez-Kábana, R. (1986) Organic and in-organic amendments to soil as nematode suppressants. *Journal of Nematology* 18, 129-135.

Rodríguez-Kábana, R. and King, P.S. (1980) Uses of mixtures of urea and blackstrap molasses for control of root knot nematodes in soil. *Nematropica* 10, 38-44.

Rodríguez-Kábana, R., Shelby, R.A., King, P.S. and Pope, M.H. (1982) Combinations of anyhrous ammonia and 1,3-dichloropropenes for control of root-knot nematodes in soybean. *Nematropica* 12, 61-69.

Rosemeyer, M., Viane, N., Swartz, H. and Kettler, J. (2000) The effect of slash/mulch and alleycropping bean production systems on soil microbiota in the tropics. *Applied Soil Ecology* 15, 49-59.

Sainz, M.J., Taboada-Castro, M.T. and Vilarino, A. (1998) Growth and mineral nutrition and mycorrhizal colonisation of red clover and cucumber plants grown in soil amended with composted urban wastes. *Plant and Soil* 205, 85-92.

Scheuerell, S. and Mahafee, W. (2002a) Compost tea: principles and prospects for plant disease control. *Compost Science and Utilization* 10, 313-338.

Scheuerell, S. and Mahafee, W. (2002b) Assessing aerated and nonaerated watery fermented compost tea and *Trichoderma harzianum* T-22 for control of powdery mildew (*Sphaerotheca pannos* var. rosae) of rose in the Willamette valley, Oregon (abstract). *Phytopathology* 90, 69.

Schueler, C., Biala, J. and Vogtmann, H. (1989) Antiphytopathogenic properties of biogenic waste compost. *Agriculture, Ecosystems and Environment* 27, 477-482.

Schutter, M.E. and Fuhrmann, J.J. (2001) Soil microbial community responses to fly ash amendment as revealed by analyses of whole soils and bacterial isolates*. Soil Biology and Biochemistry* 33, 1947-1958.

Sekiguchi, A. (1977) Control of fusarium wilt on chinese yam. *Annual Report of the Department of Plant Pathology, Entomology, Vegetables and Floriculture Nagano Experimental Station, Japan* 1, 10-11.

Serra-Wittling, C., Houot, S. and Alabouvette, C. (1996). Increased soil suppressiveness to fusarium wilt of flax after addition of municipal solid waste compost*. Soil Biology and Biochemistry* 28, 1207-1214.

Serra-Wittling, C., Houot, S. and Barriuso, E. (1995) Soil enzymaticc response to additions of municipal solid waste compost. *Biology and Fertility of Soils* 20, 226-236.

Shepherd, M., Harrison, R., Cuttle, S., Johnson, B., Shannon, D., Gosling, P. and Rayns, F. (2000). Understanding fertility in organically managed soils. Scientific literature review undertaken as part of DEFRA research contract OF 0164.

Soil Association (2002) *Standards for organic farming and production 2002/2003.* Soil Association, Bristol. UK.

Soil Association (2002). *Organic Food and Farming Report 2002*. Soil Association, Bristol. UK.

Spring, D.E., Ellis, M.A., Spotts, R.A., Hoitink, H.A.J., Schmitthenner, A.F. (1980) Suppression of the apple collar rot pathogen in composted hardwood bark. *Phytopathology* 70, 1209-1212.

St John, T.V., Coleman, D.C. and Read, C.P.P. (1983) Association of vesicular-arbuscular mycorrhizal hyphae with organic particles. *Ecology* 64, 957-959.

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. and Watson, C.A. (2001). Agronomic and Environmental Implications of Organic Farming Systems. *Advances in Agronomy* 70, 261-327.

Sumner, D.R. and Boosalis, M.G. (1981) Effects of reduced tillage and multiple cropping on plant diseases. *Annual Review of Phytopathology* 19, 167-187.

Tiquia, S.M., Lloyd, J., Herms, D.A., Hoitink, H.A.J. and Michel, F.C. (2002) Effects of mulcing and fertilisation on soil nutrients, microbial activity and rhizosphere bacterial community strcture determined by analysis of TRFLPs of PCR-amplified 16srRNA genes. *Applied Soil Ecology*, In Press.

Theunissen, J. (1997) Application of intercropping in organic agriculture. *Entomological Research in Organic Agriculture* 12, 251-259.

Tränkner, A. (1992) Use of agricultural and municipal organic wastes to develop suppressiveness to plant pathogens. In: E.S. Tjamos, G.C. Papavizas and R.J. Cook (eds.) *Biological control of plant diseases*. Plenum Press, New York, USA, pp 35-42.

Tsror [Lakhim], L., Barak, R. and Sneh, B. (2001) Biological control of black scurf on potato under organic management. *Crop Protection* 20, 145-150.

UKROFS (2001) United Kingdom Register of Organic Food Standards - Standards for organic food production. http://www.defra.gov.uk/farm/organic/ukrofs/standard.pdf

van Bruggen, A.H.C. (1995) Plant disease severity in high-input compared to reduced input and organic farming systems. *Plant Disease* 79, 976-984.

van der Laan, P.A. (1956) The influence of organic manuring on the development of the potato eelworm *Heterodera rostochiensis. Nematologica* 1, 112-115.

Viane, N.M. and Abawi, G.S. (1998) Management of *Meloidogyne hapla* on lettuce in organic soil with sudangrass as a cover crop. *Plant Disease* 82, 945-952.

Voland, R.P. and Epstein, A.H. (1994) Development of suppressiveness to diseases caused by *Rhizoctonia solani* in soils amended with composted and noncomposted manure. *Plant Disease* 81, 461-466.

Wani, S.P. and Lee, K.K. (1995) Exploiting vesicular-arbuscular mycorrhizae through crop and soil management practices. *Mycorrhiza News* 6, 1-7.

Wardle, D.A. and Giller, K.E. (1996). The quest for a contemporary ecological dimension to soil biology - discussion. *Soil Biology and Biochemistry* 28, 1549-1554.

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

Welke, S. (1999) Effectiveness of compost extracts as disease suppressants in fresh market crops in BC. *Organic Farming Research Foundation. Grant Report* 19-31, Santa Cruz, California, USA.

Weltzein, H.C. (1989) Some effects of composted organic materials on plant health. *Agriculture, Ecosystems and Environment* 27, 439-446.

Weltzein, H.C (1990) The use of composted materials for leaf disease suppression in field crops. In: Crop protection in organic and low-input organic agriculture. BCPC Monographs No. 45, British Crop Protection Council, Farnham, Surrey, pp. 115-120.

Weltzein, H.C. (1991) Biocontrol of foliar fungal disease with compost extracts. pp 430-450 In: J.H. Andrews and S.S. Hirano (eds.) *Microbial ecology of leaves*. Springer-verlag, New York, USA.

Weltzein, H.C. and Ketterer, N. (1986) Control of *Phytophthora infestans* on tomato leaves and potato tubers through water extracts of composted organic wastes. *Phytopathology* 76, 1104 (abstract 372).

Weyman-Kaczmarkowa, W.; Wójcik-Wojtkowiak, D. and Politycka,B. (2002) Greenhouse medium enrichment with composted pig slurry: effect on the rooting of *Pelargonium peltatum*

Hort. cuttings and development of rhizosphere microflora. *Polish Journal of Environmental Studies* 11, 67-70.

Widmer, T.L. and Abawi, G.S. (1998) Suppressive mechanism of sudangrass incorporated as a green manure against *Meloidogyne hapla*. *Phytopathology* 88, 597.

Willson,T.C.; Paul, E.A. and Harwood, R.R. (2001) Biologically active soil organic matter fractions in sustainable cropping systems. *Applied Soil Ecology* 16, 63-76.

Wolfe, M.S. (2002) Species and varietal mixtures. In: D. Younie (ed.) *Organic Cereals and Pulses*. Chalcombe Publications, Lincoln, UK, pp 29-49.

You, M.P.; Sivasithamparam, K. and Kurtböke, D.J. (1996). Actinomycetes in organic mulch used in avocado plantations and their ability to suppress *Phytophthora cinnamomi. Biology and Fertility of Soils* 22, 237-242.

Zak, J.C. and Parkinson, D. (1983) Effects of surface amendation of two mine spoils in Alberta Canada on vesicular-arbuscular mycorrhizal development of slender wheat grass. A 4 year study. *Canadian Journal of Botany* 61, 798-803.