DEPARTMENT for ENVIRONMENT, FOOD and RURAL AFFAIRS **CSG 15**

Research and Development

Final Project Report

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Project title	Soil microbiology in organic systems - effects of composting manures and other organic wastes on soil processes and pest and disease interactions
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Executive summary (maximum 2 sides A4)

Introduction

Composts and manures are of major importance in providing fertility in organic farming systems, since synthetic fertilisers are prohibited. It is understood that composts have radically different nutrient release characteristics to those of uncomposted materials and manures, and it is believed that composting increases the beneficial effects of organic materials on soil health, soil quality, soil fertility and nutrient use efficiency. It has also been shown that some plant pests and diseases are suppressed through the application of composts and compost extracts to soils. There is considerable potential to use a wider range of feedstocks from on and off-farm sources and to improve the composting process and compost/manure application techniques. This review of scientific work to date was urgently required to help determine key research priorities in order to achieve this potential.

Project aims

1.To document the current standards, regulations and legislation relevant to recycling, compost/manure preparation and application and to review common UK practices relating to the preparation and application of uncomposted materials, manures, composts and compost extracts.
2. To review current scientific knowledge (from the literature) of the effects of different composting processes on chemical and biological parameters in the finished compost or compost extract.

3. To review (from the literature) the effects of uncomposted materials, manures and composts on soil health and quality, soil fertility and crop development and nutrition.
4. To review (from the literature) the effects of uncomposted materials, manures, composts and compost extracts on pest and disease incidence and severity in agricultural and horticultural crops.
5. To outline a proposed strategy for research which seeks to develop composting systems and compost/manure application protocols with a view to optimising soil fertility management and pest and disease control in organic agriculture and horticulture.

Objective 1 - The current standards, regulations and legislation relevant to recycling, compost/manure preparation and application are documented in detail in the full report on Objective 1 (Appendix 2). Manures and uncomposted plant materials (e.g. green manures) are commonly used on UK organic farms. True composts (defined in the glossary, Appendix 1) are rarely prepared on UK organic farms, although there is increasing interest in their use, particularly on farms producing high value horticultural crops. An increasing number of companies are producing (or are interested in producing) composts suitable for use on organic farms as soil amendments or growing media.

Objective 2 - The effects of different composting processes on chemical and biological parameters in the finished compost or compost extract are reviewed in detail in the full report on Objective 2 (Appendix 3). A short version of this review appears on pages 7-10 of this report.

Objective 3 - The effects of uncomposted materials, manures and composts on soil health and quality, soil fertility and crop development and nutrition are reviewed in detail in the full report on Objective 3 (Appendix 4). A short version of this review appears on pages 10-13 of this report.

Objective 4 - The effects of uncomposted materials, manures, composts and compost extracts on pest and disease incidence and severity in agricultural and horticultural crops are reviewed in detail in the full report on Objective 4 (Appendix 5). A short version of this review appears on pages 13-17 of this report.

Objective 5 - A proposed strategy for research was outlined which seeks to develop composting systems and compost/manure application protocols with a view to optimising soil fertility management and pest/disease control in organic agriculture/horticulture

There is little research specifically on composting in organic systems, but there is great potential to learn from the range of experience reported in the broader scientific literature. There has been an extremely limited amount of work carried out to determine the impact of organic amendments including uncomposted plant residues, composts, manures and compost extracts/teas on soils and crops in organic farming systems. A great deal of work has been done to determine the effect of organic amendments on soils and crops in conventional glasshouse and field cropping systems. Some important conclusions can be drawn from these studies, many of which have relevance to organic farming systems. However, much of this work has been done in warmer climates than that in the UK and on crops and soil types not represented in the UK.

Research is needed to quantify the short-term benefits of compost use in soil in terms of carbon sequestration and carbon dioxide fluxes. Work is needed on the Controlled Microbial Composting (CMC) system to enable it to be compared with alternative systems developed in the UK. Research is required on the bioavailability of pesticides and the fate of therapeutic agents in compost and the risks to organic farming and production systems from residues in compost feedstocks from non-organic sources. Research is also required on the survival of plant pathogens in compost, together with the development of diagnostic kits to assist in quality assurance of the finished product. Methods to determine the stability of composted materials are needed, including test kits to enable on-site testing and quality assurance.

There is a strong need for research to optimise the production and use of organic amendments based on locally available feedstocks in UK organic cropping systems if the organic farming industry is to maintain and expand its position in European and world markets. It would be helpful to develop a database of the potential benefits and disadvantages of commonly available organic amendments that are either acceptable or likely to be acceptable in organic farming. It is important to develop whole rotation approaches to studies of the effects of uncomposted materials, manures and composts on soils on organic farms. This is important to ensure that the use of such organic amendments does not exacerbate environmental problems such as nutrient losses through leaching.

Food safety and quality are high on the organic farming agenda. There is a need to develop methods for using different types of manures, composts and compost extracts/teas to improve product quality without compromising safety.

Almost no organic amendments are applied in the UK solely for the purposes of plant pest and disease control. There is increasing interest in their use for plant pest and disease control, particularly amongst organic farmers and growers, but little work has been done to optimise the use of organic amendments for this purpose in the UK climate, crops and soils.

Work is required to determine the effects of the residues of cover crops and green manures commonly grown (or with the potential to be grown) in UK organic systems on the incidence and severity of nematode populations. Research is also urgently required to optimise systems for the production of composts (using locally available feedstocks) for use on UK organic farms for the above purposes. Development of composts, compost extracts/teas and application protocols to aid in the control of soil-borne and root diseases on high value horticultural field and glasshouse crops is of the highest priority.

Organic farming systems are by nature holistic. In other words, they function as a whole and all aspects of the system are interdependent on many other aspects of the system. It is essential therefore that research which is carried out to optimise the use of uncomposted plant residues, composts, manures and compost extracts is interdisciplinary; that is it must be carried out with reference to the organic farming system as a whole and not just a single aspect of it.

Technology transfer and knowledge transfer are key elements to the proposed strategy for research. Seminars and conferences, farm walks, demonstration farms and a wide range of publishing formats must be used to ensure that end users have full access to the results of research carried out in the UK and abroad. The amount of information which is available for dissemination to those who wish to make or use composts will naturally depend on the amount of relevant research and development work which is going on in the UK, Europe and worldwide.

Scientific report (maximum 20 sides A4)

CONTENTS

INTRODUCTION

Composts and manures are of major importance in providing fertility in organic farming systems, since synthetic fertilizers are prohibited. They are in increasingly short supply, particularly in the more modern stockless systems and alternative feedstocks which are permitted under the organic standards are being sought to address these shortages. Although composting of manures and certain other wastes is encouraged by the organic principles and standards, there is a lack of information on the effects of different feedstocks, different composting methods and alteration of process parameters on the qualities of the finished product.

It is understood that composts have radically different nutrient release characteristics to those of uncomposted materials and manures, and it is believed that composting increases the beneficial effects of organic materials on soil health, soil quality, soil fertility and nutrient use efficiency. It has also been shown that some plant pests and diseases are suppressed through the application of composts and compost extracts to soils. There is considerable potential to use a wider range of feedstocks from on and off-farm sources and to improve the composting process and compost/manure application techniques. This is particularly relevant to the development of sustainable waste management strategies in England and Wales. A review of scientific work to date is urgently required to help determine key research priorities in order to achieve this potential. It is also important that this review is published in widely accessible forms to ensure that farmers and growers in England and Wales are aware of successful compost management and application strategies in other parts of the world.

AIMS OF PROJECT

The overall objectives of this project are:
1.To document the current standards, regulations and legislation relevant to recycling, compost/manure preparation and application and to review common UK practices relating to the preparation and application of uncomposted materials, manures, composts and compost extracts.
2. To review current scientific knowledge (from the literature) of the effects of different composting processes on chemical and biological parameters in the finished compost or compost extract.
3. To review (from the literature) the effects of uncomposted materials, manures and composts on soil health and quality, soil fertility and crop development and nutrition.
4. To review (from the literature) the effects of uncomposted materials, manures, composts and compost extracts on pest and disease incidence and severity in agricultural and horticultural crops.
5. To outline a proposed strategy for research which seeks to develop composting systems and compost/manure application protocols with a view to optimising soil fertility management and pest and disease control in organic agriculture and horticulture.

OBJECTIVE 1 - Documentation of the standards, regulations and legislation relevant to recycling, compost and manure preparation and application. Review of common UK practices relating to the preparation and application of uncomposted materials, manures, composts and compost extracts

The organic regulations
Both the EU and UKROFS standards emphasise that the maintenance of soil fertility and soil biological activity is a fundamental principle of organic farming. The addition of uncomposted materials, manures, composts and compost extracts (organic amendments) are acknowledged to help achieve that aim. The various types of organic amendments are defined in full in the glossary (Appendix 1). The permitted type, source and quantities of organic amendments for organic farming systems are detailed in the EU organic standards and the standards published by each of the 12 UK certification bodies. Further details are given in the full report on Objective 1 (Appendix 2).

Other regulations and guidance relating to the preparation and use of uncomposted materials, manures, composts and compost extracts
There is a considerable amount of legislation other than that specific to organic farming which affects the preparation, storage and use of organic amendments in the UK. The most important

regulations are listed below and relevant guidance and legislation is described in detail in the full report in Appendix 2.

- The Framework Directive on Waste (75/442/EEC as amended by Directive 91/156/EEC)
- Food and Environment Protection Act (1985)
- The Environment Act (1995)
- The Animal By-products Order 1999
- The Groundwater Directive 80/68/EEC
- EC Nitrates Directive (91/676/EEC
- The IPPC Directive 96/61/EC

The preparation and use of uncomposted materials, manures, composts and compost teas/extracts on UK organic farms

A range of UK organic farmers, inspectors and certification officers were interviewed during 2002 in order to establish current practice relating to the preparation and use of uncomposted materials, manures, composts and compost extracts. Uncomposted manures (e.g. green manures) and manures are widely used on UK organic farms, but true composts and compost teas/extracts are rarely used, although interest in them is increasing. The main composting system used on organic farms is the Controlled Microbial Composting or CMC System. Greater detail on the preparation and use of organic amendments on UK organic farms is given in Appendix 2.

Composting operations outside organic farms

The increased costs of landfill are encouraging waste management companies and manufacturers to re-use, recover and re-cycle wastes. A growing number of UK companies are interested in producing products suitable for use as fertilizers, soil conditioners and growing media in organic production systems. Some are already doing so and others are developing technologies, feedstock sources and markets in order to do so. The current situation is detailed in Appendix 2.

OBJECTIVE 2 - The effects of different composting processes on chemical and biological parameters in the finished compost or compost extract

Composting is an excellent example of the practical use of biotechnology. It involves a highly complex biological process, involving many species of bacteria, fungi and actinomycetes, which coverts a low-value material into a higher value product. A wide range of biowastes can be composted including materials generated by agriculture, food processing, wood processing, sewage treatment, industrial and municipal waste. There is little research specifically on composting in organic farming and production systems, therefore most of the information used in this review is based on studies carried out in conventional farming systems. However, composting and the use of composted products, e.g. composted manure, form a major component of soil fertility management in organic farming systems. There is great potential to learn from the range of experience reported in the broader scientific literature. This review is summarised here, with detailed information being provided in the full report in Appendix 3.

Composting is seen as a key process in the waste hierarchy in the UK and markets for compost have an important role in reducing the volume of biodegradable municipal waste going to landfill. The use of carbon sequestration into soil is soil one of the few tools for changing the balance of carbon in the atmosphere and can therefore help the UK in meeting the strategic goals of the climate change agreements. To make an appreciable difference there will need to be large-scale and widespread use of compost

There has been a considerable amount of work throughout the world to develop composting systems for both conventional and organic agricultural systems although few of these have been developed with UK agriculture specifically in mind. The CMC (Controlled Microbial Composting) system developed in Austria is now being developed by a range of growers and research workers for use in UK organic agriculture). However, UK organic farmers are not using composting to any significant extent at present.

The composting process
Composting relies upon an indigenous population of microbes from the environment carried by most organic materials. Temperature is the main factor that controls microbial activity during composting. Heating is essential to enable the development of a thermophilic population of microorganisms which is capable of degrading the more recalcitrant compounds (natural and anthropogenic), and to kill pathogens and weed seeds.

Aeration has an indirect effect on temperature by speeding the rate of decomposition and therefore the rate of heat production. Compost must be kept aerobic to avoid the production of odours. Moisture is essential but if the compost is too wet then anaerobic conditions develop. There may also be a build up of organic acids, such as acetic acid, which can be toxic to plants. The carbon:nitrogen ratio (C:N) is important in determining in general terms the rate of decomposition of organic materials. The optimum C:N ratio for the feedstock material is around 25. Input material can be of any solid, carbon based, biodegradable material. The PAS 100 Specification for composted materials produced by WRAP and BSI and the UKROFS regulations give details of the input materials permitted in conventional and organic systems respectively.

There are a large number of different composting systems available, ranging in technological sophistication and therefore in cost. There are open systems (windrow and aerated static pile) which are relatively simple to operate and low cost, and a number of contained systems which have options for moving the material, supplying forced air, and operating a continuous or batch system.

A considerable amount of work has been carried out to develop improved methods for preparation and use of compost extracts and teas for use as fertilizers and to assist crop protection. Most of this work has been done in the United States, mainly by commercial companies. There is some confusion as to exactly what is meant by compost teas and compost extracts. There is some evidence that non-aerated compost teas (NCTs) provide an ideal environment for the growth and reproduction of human pathogens, however this has not yet been extensively studied.

Environmental impact of composting
The composting process may generate byproducts which have potentially negative impacts on the environment, in particular gaseous byproducts. Ammonia may be volatilized from ammonium released from N-rich materials by microbial activity in the compost. Depending upon the redox conditions, microbial decomposition of organic materials will lead to the production of CO_2, N_2O, or CH_4. All of these three gases contribute to the greenhouse effect, but their net contributions to global climate change differ.

CO_2 derived from degradation of plant materials does not contribute to global warming because it had been previously removed from the atmosphere by photosynthesis. The release of N_2O and CH_4 to the atmosphere from anaerobic respiration contributes to the enhancement of the greenhouse effect. Well-managed aerobic composting systems should not make a significant contribution to greenhouse gas emissions, whereas poorly managed systems which become anaerobic can contribute to N_2O and CH_4 fluxes. Source segregation of municipal solid waste followed by recycling (for paper, textiles etc) and composting gives the lowest net flux of greenhouse gases, compared to other options for the treatment of municipal solid waste.

Manures can also act as a source of pollution to water and air. Straw-based systems are assumed to have less environmental impact than slurry, but preliminary results from controlled experiments suggest that total emissions of ammonia are similar.

The characteristics and use of composts

Composting involves converting waste material into a product that is stable and that confers beneficial effects when added to soil. Stabilization is achieved by the conversion of readily biodegradable organic compounds into less biodegradable products, in particular humus. This may also involve the stabilization of organic forms of N and P, for example by incorporation into microbial biomass. As a result these elements are less likely to be lost to the environment in leachate and gaseous emissions. Transformations of N during the composting process are important in determining the N content of the compost product and N losses. The fate of N in feedstock materials will depend upon the biodegradability of the materials and on the C:N ratio within the biodegradable fraction (this will also affect the losses of C to the atmosphere as CO_2).

The feedstock materials used for composting may contain a range of potentially toxic elements (PTEs). Upper limits for compost to be used in conventional farming are given in PAS 100. Limits for compost derived from household waste which is intended for application on organic farms are given in the UKROFS regulations. The waste material used for composting may contain contaminants (e.g. pesticides, pharmaceuticals, industrial contaminants). The fate of these compounds during the composting process will largely determine their presence in the finished product. Only the most stable compounds are likely to persist in the compost due to the length of time taken for the composting process, the intense microbial activity, and the high temperature.

Overall it appears that composting can be considered to be essentially similar to a biologically active soil environment in which degradation is accelerated. However, the bioavailability of compounds may be different due to the high content of organic matter in compost, which may sorb compounds, making them less bioavailable.

Analyses of the pesticide content in bio-waste and green waste in Germany and Luxembourg have shown a very low level, but it is unclear if this is due to strong sorption to the organic matter, or degradation.

Animal wastes from intensive farming and treated sewage (neither of which are permitted as feedstocks for compost intended for organic farms) often contain traces of therapeutic agents (compounds that are used to cure or prevent diseases). These compounds are likely to behave in the same way as pesticides in the environment, and may maintain residual activity in manure and biosolids, but have been largely overlooked.

Compost is a biological product, which (unlike peat-based products) contains a wide range of microorganisms that are beneficial to plants and the environment. In many cases, the feedstock materials will contain a number of microorganisms which are pathogenic to humans, animals and plants.

Recent attention has focussed on the risk from human pathogens associated with composting catering waste containing meat. (NB Catering wastes are not permitted as feedstocks for compost intended for use on organic farms). A risk assessment has been carried out for DEFRA and a draft statutory instrument published for consultation which specifies the processing systems and parameters that can be used for the composting of catering waste. In order to eliminate these pathogens the compost material should be raised to a minimum temperature for a minimum period of time. Where the compost is in open-air windrows, this will be a longer period of time, and these temperature regimes are often linked to requirements for turning

In addition, the composting process involves considerable changes in the biochemistry of the composted material. Antagonistic effects and breakdown of the mesophilic microbial biomass in the maturation phase can play a significant role in the elimination of pathogens and in the prevention of recolonisation of the compost by pathogens. It is impractical to monitor all of the pathogenic organisms that could be present in a feedstock and the effectiveness of the composting process on their destruction so pathogen testing usually involves testing for the presence of specific indicator micro-organisms (typically *Salmonella spp* and *E. coli*). Bioaerosols are also a concern, particularly the fungus *Aspergillus fumigatus* and its endotoxin. Emissions of bioaerosols can be minimised by maintaining moist conditions during composting or moving of material.

Livestock excreta can act as significant sources of faecal indicator organisms for recreational waters and water supplies. There is around 30 times more livestock manure recycled to agricultural land than biosolids indicating that this is a potentially important pathway of transfer of pathogens. Manure heaps encourage the formation of thermophilic conditions, particularly if turned and mixed, in which large reductions in pathogen loads can be achieved. A storage period of one month is likely to be adequate to ensure the elimination of most pathogens.

In contrast to the vast literature on survival of human pathogens there are few data on survival of plant pathogens during composting. More interest has been focussed on the disease-suppressing properties of compost. The chances of survival of fungal pathogens are very low. Even pathogens that persist in soil for years are eradicated by composting. Nematodes such as potato cyst nematode seem to be very susceptible to composting, possibly due to organic acids produced. The very few data on survival of plant viruses indicate that these pathogens are more resistant to composting than fungi and nematodes. Feedstock materials may also contain weed seeds e.g. from animal feeds or bedding material. The thermophilic conditions during composting should eliminate weed seeds.

Compost stability is an important characteristic and under certain conditions, immature, poorly stabilised composts can cause problems. Continued active decomposition when these composts are added to soil or growth media may reduce the oxygen concentration in the soil-root zone, reduce available nitrogen, or lead to the production of phytotoxic compounds. Ensuring stability of compost also reduces the potential for recolonisation of the material by human pathogens such as *Salmonella spp..*

OBJECTIVE 3 - Effects of uncomposted materials, composts and manures on soil health and quality, soil fertility, crop development and nutrition

Soil organic matter

Composts and manures have generally been shown to increase soil organic matter content, with additive effects over time. This contributes to improvement of soil structure and crop nutrition as well as to the C sequestration potential of agricultural systems.

Soil chemical properties

In relation to soil chemical properties, effects of organic matter additions vary with climate, soil type, and rate and type of organic matter used. The effect of composts and manures on soil pH depends both on the initial pH of the compost and the soil pH. They can thus be used to increase the pH of acid soils or decrease the pH of alkaline soils. Increasing pH in acid soils is beneficial in terms of improving microelement availability and reducing the solubility of some toxic elements and it is interesting to consider whether in some circumstances livestock manure/composts can substitute for lime application, thus making use of locally available resources.

Incorporation of N rich, low C:N ratio residues of fresh plant material, manures or composts leads to rapid mineralization and a large rise in soil mineral N. Generally, at C:N ratio of 15 or less mineralization occurs; above this N will be immobilized. Thus mineralization rates are usually greater from fresh material than composted material. Mineralization is also affected by a number of soil properties, in particular temperature and water content. Mineralization is also affected by soil texture and thus mineralization of N from composted and fresh organic materials is likely to be greater in sandy than clay soils. The challenge for organic farming is to manage the use of composts and manures to synchronise supply and demand for N. This requires understanding of both N release kinetics from different materials and crop growth patterns. Mixing residues of differing quality has the potential to synchronize mineralization with crop demands though the practicalities of this on a farm scale are questionable.

With continued application of composts and manures, soil P levels will increase and in soils already high in P, addition of composts and manures carries with it a risk of P runoff. It has been suggested that restricting topsoil extractable P levels to 70 mg l^{-1} should minimise these risks. A linear relationship has generally been demonstrated between added P and available soil P, regardless of compost maturity or type, suggesting that cumulative application rather than P source determines available P.

Composting of organic wastes does not appear to affect K availability but application may affect both soil K and plant K uptake. In compost K remains in water-soluble forms and thus does not need to be mineralised before becoming plant available. However, for the same reason it is at risk of leaching during the composting process and thus compost is often a poor source of K.

One of the perceived benefits of the use of composts and manures over fertilizers is their ability to provide non-NPK nutrients. Composts and manures are often reported to have beneficial effects on Ca and Mg levels in soil. Soil electrical conductivity has been shown to increase with increased manure/compost application rates. Effects will be dependent on compost type, for example, MSW has a greater effect than sewage sludge which can be detrimental in sensitive crops. Soil organic matter and clay minerals are the two most important constituents that influence soil cation exchange capacity (CEC). Coincident with results on the effect of compost on soil organic matter, compost addition is generally reported to increase CEC.

Soil physical properties

In relation to soil physical properties, the effects of organic matter additions vary with climate, soil type and texture and rate and type of organic matter. It has also been observed that a greater quantity of organic material is needed to improve soil structural properties than is necessary to supply the nutrient requirements of a growing crop. Thus economic and environmental impact must be accounted for in quantifying the value of use of organic materials.

In general, additions of manures and composts increase soil water holding capacity and porosity as well as changing pore size distribution. Effects on porosity have been shown to increase linearly with addition rate. There are also generally beneficial effects of composts and manures in reducing bulk density and penetration resistance. These result in part from the lower bulk density of the added material but are also associated with structural changes. Aggregate stability generally increases with compost and manure additions, except in very well structured soils. Although both fresh and composted materials improve aggregate stability, the mechanisms of improvement may differ. For example fresh manure can cause a decrease in stability against dissolution and disruptive forces although a more beneficial effect in resistance to slaking forces than stockpiled manure. Humic acids extracted from composted wastes have been shown to improve aggregation. For use in organic farming systems, there would be a need to find out whether such materials are acceptable within the organic standards. This is likely to depend on both the original material and the method of extraction.

Potential environmental impacts
Robust comparisons of nitrate leaching loss from composted and fresh material are not commonly reported, although there are indications that leaching is lower from composted materials. High C:N ratio wastes (e.g. paper sludge) have the capacity to immobilize N and it may be possible to exploit this property in high risk leaching situations. Compost has generally been reported to have a more beneficial effect on stabilising soils against erosion than manures. Loss of P in runoff from applied manures and composts varies with type and crop. Management of application rates and times has the capacity to reduce this but inflexibility due to storage has been cited as a constraint to putting this option into practice.

Losses of ammonia after application have been shown to be much higher from manures stored anaerobically than aerobically as they contain a much higher proportion of ammonium. Ammonia losses from composted materials have also been shown to be lower than from fresh materials. Application techniques such as incorporation have been shown to dramatically reduce ammonia loss from manures. Annual nitrous oxide emissions have been shown to increase with manure rate. Reported losses of nitrous oxide from composts are small, although significant losses have been measured from sewage sludge.

Composting of farmyard manure and anaerobic digestion of slurry have both been shown to decrease pathogen viability. *E. coli* from applied slurry has been shown to appear in drainage water in high concentrations immediately after spreading but contamination at low levels can persist for months after spreading.

Introduction of modern manufacturing processes together with source separation are changing the chemical composition of many waste materials, and the use of older literature reports may overstate possible toxic effects. Potentially toxic elements (PTEs) must still however be considered from a food chain perspective taking into account toxicity to animals and humans as well as plants and soil. Effects of added organic materials on accumulation of PTEs will depend on leaching/adsorption properties of the soil that will be strongly related to pH, texture and organic matter content. The literature suggests that phytotoxic responses to MSW at normal application rates are unlikely. In acid soils, high pH waste may be beneficial in mediating the effects of toxic elements such as Al.

Crop development and nutrition
There is a vast literature on the effects of composts and manures on yields of agricultural and horticultural crops. There are however relatively few reports in the literature of the effect of compost on yield in organic farming systems. A review of the literature highlights the fact that there is an interaction between crop and compost type. Many studies look at crop yield only in the year of application. Given the variable nature of organic amendments, there is a need to look at compost application over more than one growing season. Yield increases are generally much higher from fresh than from composted materials. Many comparisons between different materials are difficult to generalise from because of the use of different application rates of contrasting materials.

The immediate fertilizer N value of a manure or compost can be calculated from its inorganic content plus the readily mineralizable fraction. There is also a longer-term aspect to nutrient supply from organic materials regarding both the initial inorganic N content of the material and the longer-term mineralization of organic N over several years. Information on the effects of manures and composts on crop nutrition in organic systems is still limited, although more is now becoming available. One of the challenges for sustainable use of manures and composts is that manure or compost application to provide N may over supply P. This is because the N/P ratio of manures and composts is significantly smaller than the N/P uptake ratio of most crops. Compost maturity affects crop nutrient uptake, for example, higher P uptake from mature and raw poultry manure than from immature composts that caused P immobilisation in soil. By contrast, potassium in organic wastes is as available as it is in mineral fertilizers. Organic materials are often valued for the addition of minor elements to soils at no extra cost. In organic systems they are essential for both recycling nutrient within the farming system and replacing nutrients sold in produce. The literature however generally concentrates on N, P, K and PTEs.

Tools

Improving soil fertility in organic farming through the use of composts relies on improved understanding of the effects of feedstocks, composting and application methods on soil fertility and also on improved technology transfer of research results into practice. This requires the provision of good on-farm advice by advisors who fully understand the complexity of managing soil fertility in organic farming systems. Farmers often underestimate the nutrient values of organic materials and thus analyses of materials prior to application are a constructive educational tool. It is a challenge to develop user-friendly tools that can predict nutrient transformations from added organic materials to meet crop demand and avoid N losses by leaching and volatilization and P losses by run-off. There are an increasing number of models being developed but most are not adapted for organic farming conditions. These are discussed in detail in the full report on Objective 3 (Appendix 4).

Systems aspects

In making recommendations for compost use in organic agriculture, the rotational aspects of the system need to be taken into account. On organic farms, where the importation of materials to build/maintain soil fertility is restricted, it is important that a balance between nutrient input and output is achieved to ensure both short-term productivity and long-term sustainability. Soil management must be understood, planned and managed over periods of longer than a single crop or growing season.

OBJECTIVE 4 The effects of uncomposted materials, composts, manures and compost extracts on beneficial microorganisms and pest and disease incidence and severity in agricultural and horticultural crops

Crop health and soil biology in organic agriculture and horticulture

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 review carried out under Objective 4 evaluates this evidence in relation to modern organic agriculture. This review is summarised here, with detailed information being provided in the full report in Appendix 5.

Organic farming systems aim for efficient nutrient cycling through the maintenance of a large and diverse population of soil organisms. 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. There is little or no application of organic amendments specifically for the purpose of preventing or controlling pests or diseases in UK organic crops at present.

However, conventional and organic farmers in parts of Europe and the United States are reported to be applying disease suppressive composts and compost teas with some success.

Effects on beneficial microorganisms

The impact of uncomposted materials, composts, manures and compost extracts on soil microbial activity has been evaluated on the whole microbial community and on specific key soil microbial groups. Some specific soil microbial groups are known to play an integral role in plant growth, development and productivity, control of soil borne pathogens and soil fertility. The impact of organic amendments to the soil microbial community can be measured in several ways. Soil microbial biomass carbon (C_{mic}) is a sensitive indicator of microbial biomass. Upon application of uncomposted materials, composts, manures and compost extracts the C_{mic} always increases. However, this increase is transient and usually declines over time with the exhaustion of readily available nutrients. The responses of soil enzymatic activities are indicative of the global activity of microorganisms and provide indications of soil fertility. These enzymatic activities are also affected by soil amendments. The responses of specific enzymes such as soil hydrolyases and dehydrogenases are particularly sensitive to the chemical composition of the compost and the soil to which the amendment is being added. Dehydrogenase, protease, catalase and arylsulphatase enzymatic activity is consistently increased and/or does not change significantly on application of the amendment to the soil. Enzymatic activities such as urease and phosphatase are much more variable, with decreases in activity often observed. However, these enzymes are much more sensitive to the polyphenol and heavy metal contents of the amendments respectively.

The structure and metabolic diversity of soil microbial communities within the rhizosphere and bulk soil have been demonstrated to be altered by the amendment of uncomposted materials, composts, manure's and compost extracts to soils. The shifts in community structure and functioning often reflect the indigenous soil microbial species that can utilise and survive on the chemical constituents and breakdown products of the soil amendment. The shifts in the microbial communities are also due to the fact that amendments have their own microbial communities, which will interact with the indigenous soil community. However, although there will be initial fluctuations in the microbial community structure post-soil amendment, there is a tendency over time for the amended soil to revert back to a population structure that was present pre-soil amendment. However, communities of biological control microorganisms are often enhanced and/or promoted in amended soil.

The impact of uncomposted materials, composts, manure's and compost extracts to soils on beneficial soil microorganisms, incidence, activity and population structure has been variable. This variation in response can range from the positive through no effect to negative effects and the variation holds true for all species of beneficial soil microorganisms evaluated within this study. The beneficial soil microorganisms evaluated included fungi (arbuscular mycorrhizal fungi, ectomycorrhizal fungi, nematode trapping fungi and species of *Trichoderma*), nematodes (bacterivorous and fungivorous nematodes) and bacteria (symbiotic and free living nitrogen fixing microorganisms, plant growth promoting rhizosphere bacteria (PGPR), fluorescent *Pseudomonas* spp., actinomycetes and autotrophic ammonia oxidising bacteria). Overall, the response of beneficial microorganisms was dependent on several factors, these included: -

- chemical composition of the amendment.
- microbial community of the amendment.
- physical structure of the amendment and the evenness of application to the soil.
- soil type to which the amendment was added.
- plant species subsequently grown in the short and long-term after the soil amendment.
- environmental conditions (e.g. temperature and rainfall) subsequent to the soil amendment.

Impact of uncomposted materials, composts, manures and compost extracts on pests and diseases

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.

<u>Uncomposted plant residues</u>

Much work has been done to show that uncomposted plant residues (including green manures) can reduce incidence and severity of damage caused by plant parasitic nematodes. There is a limited amount of information on the impact of plant residues on crop diseases, but the effects are variable. Although there is potential to use uncomposted plant residues to help suppress plant parasitic nematodes or diseases, the efficacy of these residues is highly variable depending on the type of crop residue, the crop and cropping system, soil type, climate etc. There has been insufficient work done to allow reliable prediction of the effects of uncomposted plant residues on crop yield and plant disease incidence and severity in the UK.

<u>Composts</u>

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. However, not all studies have reported such success: several workers have reported no effects or variable effects of composts on nematode populations. Much of this variability between reports from different researchers 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. 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.

The potential for composts to suppress root and soilborne disease is now well documented, with the greatest successes having been reported in conventional container production systems. 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. There are increasing examples of disease suppression following application of composts to field soils and some of this work relates to organic as well as conventional farming systems. However, 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. The efficacy of composts in suppressing plant disease is 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.

<u>Manures</u>

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 and to reduce populations of plant-parasitic nematodes and damage caused by them in a few cases. The impact of manures on pest and disease incidence and severity is less predictable than that of composts and increased pest or disease attack as a result of manure application has been recorded.

Compost extracts and teas

Compost extracts and teas are defined in the glossary in Appendix 1 and methods for their preparation are detailed in the full report on Objective 4 (Appendix 5). 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. 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. 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. However very little work has been done to quantify the benefits from using compost teas in this way.

Mechanisms of control and factors affecting control of diseases using uncomposted materials, composts, manures and compost extracts

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. 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. 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". 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. 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.

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. 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.

Compost teas sprayed on to plant leaves act directly on the leaf surface. The principal active agents in compost teas appear to be bacteria in the genera *Bacillus, Serratia* and fungi in the genera *Penicillium* and *Trichoderma*, although other genera are involved. Compost teas act in one or more of three ways including: i) inhibition of spore germination, ii) antagonism and competition with pathogens and iii) induced resistance against pathogens. The main effects of compost extracts appear to be associated with live microorganisms, since sterilised or micron filtered compost extracts have usually been shown to have significantly reduced activity against test pathogens. The phenomenon of induced or acquired systemic resistance may also explain part of the mode of action of some compost extracts/teas. Research suggests that different preparation methods and different composts and application methods affect the qualities and efficacy of the final product.

OBJECTIVE 5 Proposed strategy for research which seeks to develop composting systems and compost/manure application protocols with a view to optimising soil fertility management and pest/disease control in organic agriculture/horticulture

Introduction

Organic production systems aim to increase soil biological activity, maintain long-term soil fertility, recycle wastes of plant and animal origin in order to return nutrients to the land, and rely on renewable resources in locally organised agricultural systems. It was realised early on in the development of organic farming that natural humus formation in soil is a slow process which cannot match the rate of depletion under heavy cropping. The proposed solution was to manufacture humus outside the soil, by stacking or composting organic wastes, and then apply the finished product to the land. However, true composting is not being done to any great extent at the present time on UK organic farms. Biodynamic farmers are more likely to make compost, but this is generally done on a small scale.

More generally, the management of biowaste through composting impacts on climate change and can have a beneficial effect on soil quality and farming practices. Composting can therefore contribute to a wide range of environmental objectives as well as contributing to sustainable farming systems. Composting helps to reduce the amount of biodegradable waste (70% of the municipal waste stream going) to landfill. Managing the biowaste stream in a sustainable way can also assist in a number of other areas including:

- tackling climate change in the medium term through the sequestration of carbon whilst long term reductions are made
- replacing organic matter in the soil reversing soil degradation and improving biological diversity and activity, soil fertility and the ability of soil to retain moisture

- diversification of farming income through compost processing
- bulking out of peat products to reduce pressure on peat bogs
- providing a material to help restore contaminated land to productive use

It is clear that the encouragement of composting and compost use in farming should be viewed as an agri-environmental measure, and should be supported accordingly in organic and conventional farming and production systems. The production and use of compost on organic farms in the UK is likely to increase in the future as the result of a number of additional drivers. For organic growers in particular, the use of raw manures on soil used to produce ready to eat crops has come under increased scrutiny over recent years due to fears over pathogen safety. As a consequence the Soil Association has developed recommendations within its standards encouraging growers to compost manures and to allow time intervals between application of fresh manure and the harvest of ready to eat crops. The Food Standards Agency (FSA) is also investigating this issue and is in the process of producing guidelines for the safe use of manures on ready to eat crops. The FSA guidelines will encourage the use of compost and suggest time intervals between application of manure and crop harvest/planting. These guidelines will not become statutory for all vegetable producers, but it is likely that UKROFS will adopt the key recommendations within their standards. In this event all organic growers in the UK will be required to comply.

There are also a number of obstacles to increased compost use. The European regulations (EU 2092/91) for organic farming are constantly evolving. For example, up until 31st March 2002 the regulation allowed the use of green waste compost and compost derived from household waste. However, the use of nutrient sources not originating from organic farming could be reviewed and limited in the future. This would restrict the potential for organic producers to make use of waste derived composts. In addition, the regulation prohibits the use of genetically modified organisms (GMOs) in organic farming. It is highly unlikely that this rule will change in the near future. The extent to which this requirement is implemented varies. The Soil Association currently prohibits the use of compost derived from household waste owing to the potential for contamination via this route. If GMOs are accepted for commercial use in UK agriculture and amenity horticulture it will be increasing difficult to ensure that waste streams are free from contamination.

Food retailers and processors are concerned about the potential risk of pathogen contamination of food caused by manure-derived materials. The supply chain could seek to eliminate this risk by striving for sterile production and processing systems. This would threaten the potential for development of the use of composts and compost extracts. It would also lead to a range of other environmental problems associated with increased use of soluble fertilizers and pesticides

There has been an extremely limited amount of work carried out to determine the impact of organic amendments including uncomposted plant residues, composts, manures and compost extracts/teas on soils and crops in organic farming systems. A great deal of work has been done to determine the effect of organic amendments on soils and crops in conventional glasshouse and field cropping systems. Some important conclusions can be drawn from these studies, many of which have relevance to organic farming systems. However, much of this work has been done in warmer climates than that in the UK and on crops and soil types not represented in the UK.

There is a strong need for research to optimise the production and use of organic amendments based on locally available feedstocks in UK organic cropping systems if the organic farming industry is to maintain and expand its position in European and world markets. Research priorities determined following the reviews carried out for Objectives 2 to 4 are discussed individually in sections 5.2 to 5.4 and the need for a holistic research strategy concerning the preparation and use of organic amendments for the organic farming industry is discussed in section 5.5

Research priorities identified under Objective 2

There is little research specifically on composting in organic farming and production systems, therefore most of the information is based on studies carried out in conventional farming system. However, composting and the use of composted products, e.g. composted manure, forms a major component of soil fertility management in organic farming systems. There is great potential to learn from the range of experience reported in the broader scientific literature. This requires greater effort to be put into technical transfer of current knowledge on composting to inform organic farmers and growers, and regulators about issues of concern.

The priorities for research identified under Objective 2 are summarised in Table 5a. The use of carbon sequestration into soil is soil one of the few tools for changing the balance of carbon in the atmosphere and can therefore help the UK in meeting the strategic goals of the climate change agreements. To make an appreciable difference there will need to be large-scale and widespread use of compost. Further research is needed to quantify the short-term benefits of compost use in soil in terms of carbon sequestration and carbon dioxide fluxes.

There has been a considerable amount of work throughout the world to develop composting systems for both conventional and organic agricultural systems although few of these have been developed with UK agriculture specifically in mind. The CMC (Controlled Microbial Composting) system developed in Austria is now being developed by a range of growers and research workers for use in UK organic agriculture). Research is needed on the CMC system to enable it to be compared with alternative systems developed in the UK.

Empirical relationships exist between process variables such as C:N ratio of input materials, moisture contents, aeration status and the quality of the finished product. There is a need to establish more rigorous process models that enable the composting of a variety of materials by a variety of alternative methods in order to produce finished compost of a suitable quality for a number of different purposes (soil conditioner, fertilizer, plant disease suppression).

A considerable amount of work has been carried out to develop improved methods for preparation and use of compost extracts and teas for use as fertilizers and to assist crop protection. Most of this work has been done in the United States and much of it by commercial companies. There is an urgent need for research on the efficacy of these products and risk assessments on the colonisation of non-aerated compost teas by human pathogens.

The feedstock materials used for composting may contain a range of potentially toxic elements (PTEs) and upper limits have been proposed for conventional and organic farming systems. These limits should take into account the bioavailability of PTEs in compost immediately following incorporation into soil and over time as the compost is decomposed.

Overall it appears that composting can be considered to be essentially similar to a biologically active soil environment in which degradation is accelerated. However, the bioavailability of compounds may be different due to the high content of organic matter in compost, which may sorb compounds, making them less bioavailable. Research is needed on the bioavailability of pesticides in compost and the risks to organic farming and production systems from residues in compost feedstocks from non-organic sources.

Animal wastes from intensive farming and treated sewage often contain traces of therapeutic agents (compounds that are used to cure or prevent diseases). These compounds are likely to behave in the same way as pesticides in the environment, and may maintain residual activity in manure and biosolids. Research is needed on the fate of therapeutic agents in compost and the risks to organic farming and production systems from residues in compost feedstocks from non-organic sources.

There has been concern over the fate of human pathogens in manures and compost, in particular catering waste containing meat. Further work is needed to quantify the pathogen populations associated with the range of feedstocks likely to be, and to measure the effectiveness of different systems in achieving the required pathogen kill. Novel technologies should be investigated which will assist in the production of safe products for use in organic farming and production systems.

Research is needed on the survival of plant pathogens in compost, together with the development of diagnostic kits to assist in quality assurance of the finished product.

Compost stability is an important characteristic in terms of the effectiveness of the compost in supporting increased plant growth, and also in reducing the potential for recolonisation of the material by human pathogens. Research is needed on methods for determining stability of composted materials, including test kits to enable on-site testing and quality assurance.

Research priorities identified under Objective 3

A review of the literature indicates a large research base on the effects of manures and composts on soils, the environment and crop growth and nutrition. While the general effects of the use of composts and manures on soil physical and chemical properties are well understood, the interactions between composts and manures, soil properties, tillage and rotation are less well characterised. The priorities for research identified under Objective 3 are summarised in Table 5b. There is very little information on compost use in organic farming systems. Much basic information is transferable between the two systems, but it is important to develop good, practical guidelines for compost use in organic systems based on a rotation/systems approach.

Published research suggests that gaseous nitrogen losses tend to be lower from composted than fresh organic materials, but management options to minimise these losses need further development. There is also a need to investigate trade-off's between different gaseous and leaching forms of pollutants following compost application (including methane and carbon dioxide). The potential for using high C:N ratio materials to minimize losses has been demonstrated experimentally. Within organic systems it would be helpful to assess the feasibility of developing mixtures of materials for specific soil management/crop nutrition purposes. Mixing of slowly available mineral materials (e.g. rock phosphate) with organic materials low in P should also be invetsigated.

Food safety and quality are high on the organic farming agenda. There is a need to develop methods for using different types of manures and composts to improve product quality without compromising safety. For example, top-dressing with slurry could improve grain protein but the risk of human pathogen transfer needs to be fully addressed. This is part of a wider need to assess the issue of whether the human health risks of using manure/composts in organic systems is really any different than in conventional systems.

We need a joined-up approach to management decisions in relation to compost and manure use in organic farming. It would be helpful to develop a database of the potential benefits/disbenefits of a number of commonly available materials that are either a) acceptable in organic farming or b) likely to be acceptable in organic farming. In relation to b) the way forward may be to use a life cycle assessment approach to determine criteria/acceptability. This would need to include factors such as source, solubility, manufacturing processes, local availability etc. It might be interesting, for example, to consider whether manures or composts could be used as a liming material as a working example of the proximity principle. From a database of this type it would then be possible to develop application guidelines for the use of different materials to address different crop nutrition/soil management situations. This would also contribute to the continued evolution of the organic farming standards.

Finally, a major challenge is to develop user-friendly tools that can predict nutrient transformations from added organic materials to meet crop demand and avoid N losses by leaching and volatilization and P losses by run-off. Many of the tools developed for conventional farming could be (and are being) adapted for use in organic farming systems.

Research priorities identified under Objective 4

Uncomposted plant residues, composts, manures and compost extracts are being used widely throughout the world, but most are applied mainly for nutritional and soil improvement purposes. Almost no organic amendments are applied in the UK solely for the purposes of plant pest and disease control. There is increasing interest in their use for plant pest and disease control, particularly amongst organic farmers and growers, but little work has been done to optimise the use of organic amendments for this purpose in the UK climate, crops and soils. The priorities for research on the potential for use of organic amendments for plant pest and disease control are summarised in Table 5c.

Cover crops and green manures are a common feature of organic rotations in the UK. Some types of uncomposted plant residues have been shown to reduce populations of plant parasitic nematodes and the damage that they cause. Work is required to determine the effects of the residues of cover crops and green manures commonly grown (or with the potential to be grown) in UK organic systems on the incidence and severity of pest populations (especially plant parasitic nematodes in crops such as potatoes and other root and tuber crops).

Stacked manures and composts are often applied on UK organic farms, but little is known about the effect of such organic amendments on pests, diseases and populations of beneficial microorganisms in UK soils. Review of the literature has suggested that true composts are the form of organic amendment most likely to help prevent and control pests and diseases and most likely to enhance the numbers and biodiversity amongst populations of beneficial microorganisms. Research is urgently required to optimise systems for the production of composts (using locally available feedstocks) for use on UK organic farms for the above purposes. Development of composts and application protocols to aid in the control of soil-borne and root diseases on high value horticultural field and glasshouse crops is of the highest priority. Some examples of diseases of particular importance in UK organic farming systems (for which research has shown that there is the potential for control or partial control using composts) include: wirestem and clubroot of brassicas, redcore and verticillium wilt of strawberries, fusarium wilts and phytophthora and pythium root rots of various crop species, white rot of onion and skin diseases of potato.

Reports on work carried out in Europe and the United States show that some types of compost extracts/teas can help prevent and control several foliar pathogens in experimental situations and in conventional field and glasshouse production systems. 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, up till now 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 and much of the information relating to preparation and application methods used there for compost extracts/teas is available free on the internet. Considerable work is required however, to develop and adapt the techniques currently used in the United States for use on UK organic crops. Some examples of foliar diseases of particular importance in UK organic farming systems (for which research has shown that there is the potential for control or partial control using compost teas/extracts) include: powdery mildews of fruit, salad and vegetable crops, scab on apples, blight on potato and grey mould on soft fruit.

There is evidence to show that human pathogens can grow during the production of both aerated and nonaerated compost teas. However, the indications are that pathogen growth is not supported when the teas are prepared without fermentation nutrients. Further work is urgently 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. Work is also required to develop safe systems of compost production and use to reduce the potential for contamination of fresh produce with human pathogens

Conclusions

Organic farming systems are by nature holistic. In other words, they function as a whole and all aspects of the system are interdependent on many other aspects of the system. It is essential therefore that research which is carried out to optimise the use of uncomposted plant residues, composts, manures and compost extracts is interdisciplinary; that is it must be carried out with reference to the organic farming system as a whole and not just a single aspect of it

The organic production systems approach to agriculture and the environment is highly relevant to many of the current issues being more widely addressed at the European and UK levels. Organic systems are therefore at the centre of policy and research. There are a number of policy areas which are converging on composting and soil management, in particular soil organic matter. Research is required to inform policy (government legislation and EU and UK organic regulations) about the safety, benefits and environmental implications of composting different types of waste, (e.g. household waste) some of which may be suitable for use in organic farming systems.

In economic terms, farmers in general are seeking to diversify and the processing of compost is one form of income that that could prove successful. However, much effort will need to be put into developing markets for compost products. The broad issues are similar for organic and conventional farming systems and include:

- the need to inform farmers and growers about the wide range of benefits arising from the use of compost,
- cost benefit analysis of the production and application of composts and manures
- concerns from farmers about the quality of compost, particularly in relation to human and plant pathogens (and, to a lesser extent in organic systems) residues of pesticides and therapeutic agents,
- the different requirements and loading tolerances of soil across the UK, for example the need to protect Nitrate Vulnerable Zones,
- transport and logistical implications, in particular where farms are remote from sources of suitable feedstocks and finished products,
- implications of the Animal By Products Order in relation to composting catering waste.

There are also important differences between organic and conventional farming systems in relation to compost, for example in the feedstock materials permitted, which are more restricted in the case of organic farming systems. As we learn more about the transformations of materials, including pesticides, therapeutic agents and GMOs during the intensive thermophilic stage and more sustained mesophilic stage, it may be that composting reveals itself to be an appropriate gateway enabling a wider range of feedstock materials (including some from non-organic sources) to be processed into a conditions that is suitable for use in organic farming and production systems.

Technology transfer and knowledge transfer are key elements to the strategy proposed here. For example, the Soil Association is developing composting demonstration farms as best practice models for producers/ local authorities/waste generators and the general public to visit and learn from. The amount of information which is available for dissemination to those who wish to make or use composts will naturally depend on the amount of relevant research and development work which is going on in the UK, Europe and worldwide.

The concept of Soil Health could prove useful in raising awareness among farmers and growers about (a) the need to manage the biological component of soil in a sustainable manner (b) the need to supply soil with high quality organic materials to enhance soil microbial diversity and activity. The experiences of the US Department of Agriculture with the Soil Field Test Kit could be relevant. The use of simple field-based methods for measuring soil respiration and earthworm numbers can inform and empower the end-user by allowing the impact of different soil organic matter management strategies to be assessed quickly and easily.

PLANNED PUBLICATIONS

The following publications are in preparation and are planned for submission in 2003

Planned refereed publications

1. A scientific review on the impact of uncomposted plant residues, composts, manures and compost extracts on soil fertility and crop nutrition. Target journal - Advances in Agronomy

2. A scientific review on the impact of uncomposted plant residues, composts, manures and compost extracts on soil health and beneficial organisms. Target journal - Applied Soil Ecology

3. A scientific review on the impact of uncomposted plant residues, composts, manures and compost extracts on plant pests and diseases. Target journal - Plant Disease

Planned technical guide

1. Best practice soil management on organic farms. Input to draft Soil Association Technical guide

Planned trade press/popular articles

1. An article on the main findings from the project. Target journal - Organic Farming

2. An article on the potential and problems relating to compost teas in organic farming. Target journal - Organic Farming

3. The potential for pest and disease control using composts and compost teas – Target journal - Ecology and Farming

TECHNOLOGY TRANSFER EVENTS

Farm walks

<u>Farm name and location</u> Terling Farms, Terling, Essex
<u>Date</u> 11.06.02

Purpose To introduce farmers to the aims of the DEFRA project and to walk around field trials to demonstrate compost use in agriculture.
Audience Fourteen farmers and composters from the South East of England

Seminars/conferences (past)
Title Horticulture Symposium (The Soil Association)
Location Stockbridge Technology Centre, Selby, Yorkshire
Date: 17.09.02
Presentation(s) made
1. Nutrient budgeting in organic horticulture – making it add up without manure (Christine Watson)
2. Composts and manures - more than just fertilizers (Audrey Litterick)

Audience Around 200 delegates including farmers, growers, policymakers, retailers and wholesalers from all over the UK (Soil Association members and non-members)

Title Fertile farming
Location Burnside Farm, Memus, Forfar and The Torr, Auchencairn, Castle Douglas
Date 12.11.02 (Forfar); 13.11.02 (Castle Douglas)
Presentation(s) made
1. Nutrient budgeting in organic horticulture and the role of composts (Christine Watson)
2. Composts and manures - more than just fertilizers (Audrey Litterick)

Audience Around 30 delegates at each seminar including farmers, growers and organic inspectors from Scotland and the north of England (Soil Association members and non-members)

Seminars/conferences (future)
Title Compost and soil - the foundations for health (A two day conference)
Location Holme Lacey College, Hereford
Date 30 April - 1 May 2003
Presentation(s) to be made (The entire project team will be involved in this dedicated conference)
1. How to make good compost
2. Understanding soil profiles
3. Understanding soil biodiversity and its importance for sustainable agriculture
4. The potential of compost teas
5. Minimum cultivation systems - benefits and drawbacks
6. Measuring soil health - where are we and where to we need to be going
7. Tailoring compost for disease suppression

Audience The Soil Association are allowing for around 200 delegates including farmers, growers, policymakers, retailers and wholesalers from all over the UK (Soil Association members and non-members)

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Table 5a Objective 2 Research priorities for UK organic agriculture and horticulture (the effects of different composting processes on chemical and biological parameters in the finished compost or compost extract)*.

	Composts/manures			Compost teas/extracts	
	Feedstocks	Composting system	Maturity	Preparation	Source compost
Greenhouse gases and carbon sequestration	●●●	●●●	●●●	N	N
Nitrogen and ammonia	●●●	●●●	●●●	N	N
Potentially toxic elements (PTEs)	●●●	●	●●	N	N
Pesticide residues	●●	●●●	●●	●●	●●
Therapeutic agent residues	●●	●●●	●●	●●	●●
Human pathogens in material	●●	●●●	●●●	●●●	●●
Plant pathogens in material	●●	●●●	●●●	●	●

* N = not a significant research priority; ● = low priority; ●● medium priority; ●●● high priority

Table 5b Objective 3 Research priorities for UK organic agriculture and horticulture (effects of uncomposted materials, composts and manures on soil health and quality, soil fertility, crop development and nutrition)*

	Composts/manures		
	Feedstocks	Maturity	Application strategy
Soil organic matter	●	●	N
Soil chemical properties	●	●	N
Soil physical properties	●	●	●●
Nitrate leaching	●	●	●●●
Runoff and erosion	●	●●	●●
Gaseous losses	●	●	●●●
Human pathogens	●●●	●●●	●●●
PTEs	●	●●	●●
Yield	●	●	●●
Crop nutrition	●	●	●●
Product quality	●●●	●●●	●
Tools and models	N	N	●●●
Systems aspects	●●●	●●●	●●●

*N = not a significant research priority; ● = low priority; ●● medium priority; ●●● high priority

Table 5c Objective 4 Research priorities for UK organic agriculture and horticulture (effects of uncomposted materials, composts, manures and compost extracts on beneficial microbes, pest and disease incidence and severity in agricultural and horticultural crops).*

		Composts/manures				Compost extracts/teas		
Effect on	Uncomposted plant residues	Feedstocks	Composting system	Maturity	Application strategy	Preparation	Source compost	Application strategy
Specific beneficial microbes	●	●●	●	●●	●	●●	●●	●●
Microbial populations	●	●	●	●	●	●	●	●
Plant parasitic nematodes	●●●	N	●	●	●	N	N	N
Other soil-borne pests	●	N	N	N	N	N	N	N
Foliar Disease	N	N	N	N	N	●●●	●●●	●●●
Soil-borne/root disease	●	●●●	●●●	●●●	●●●	●	●	●●
Human/animal pathogens	●	●●●	●●●	●●●	●●●	●●●	●●●	●●

* N = not a significant research priority; ● = low priority; ●● medium priority; ●●● high priority