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RESEARCH TOPIC REVIEW: Compost: the effect on nutrients, soil health and crop quantity and quality

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1. Scope and Objectives of the Research Topic Review:

The primary scope of this review is to provide evidence for the effects of compost as distinct from the effects of fresh or stored manure. It is intended to help advisers and farmers identify when the use of compost or a composting process is appropriate. This review is not intended to address the detailed issues surrounding the production of compost in its various forms though it is proposed to include some basic information with particular respect to on-farm composting operations. The differences between well-made compost and semi compost (single turned) that may be revealed by this review could inform decisions about the approach taken to composting in an on-farm situation.

The specific issues to be addressed by this review will include the following:

- The different types of compost available to producers, and their qualities and properties.
- The role of composts in disease suppression and, where shown, the mechanism for any effects.
- The direct and indirect effects on crop yields.
- Detectable and measurable effects on crop quality (an appropriate definition of quality will be required).
- The effects of compost applications on soil biology and organic matter levels, and the implications for carbon sequestration.
- The most appropriate situations for the use of compost as opposed to fresh manure.
- This has a particular relevance in the production of ready to eat horticultural crops

This review will not be covering the use of bulky organic materials generated by fermentation or anaerobic types of process such as biogas generation. A considerable amount of work has been done on this topic on mainland Europe but the use of fermentation processes is relatively uncommon in the UK. Compost teas will also be left outside the scope of the review in the interest of focusing on the uses and effects of solid composts. Both these types of material could feature in a follow up review. A further topic that could benefit from a later review is the use of compost(s) in growing media for plant raising and production. There will be no discussion of sewage sludge or any materials derived from it or containing it – the use of such products are not permitted under the terms of EU Regulation 2092/91 or the UK Compendium of Organic Standards.

2. Summary of Research Projects and the Results

Fuchs, Bieri and Chardonnens (Eds. 2004) FiBL Report on "Effects of compost on the environment, soil fertility and plant health"

This report has a literature review summary written in English but does not give any references. It is however a useful and detailed overview. There was some discussion of composting standards and Swiss legislation to start before the chapter went through several technical sections.

In general terms compost will modify soil organic matter (SOM) levels depending on compost quality and when/where applied. This often leads to increases in organic carbon and total nitrogen in topsoil. Equilibrium is achieved after long periods of time and this is affected by soil type, climate, the means of exploitation and the quality/quantity of the compost. Soil pH is generally increased or stabilised – this can save lime inputs in some circumstances. The cation exchange capacity (CEC) of SOM is higher than that of clay minerals so raising SOM will lift overall soil CEC.

In terms of the effects on physical properties compost use can lead to larger and more stable aggregates. This occurs in the short term (< 3 years) and is maintained with continuous applications. Mature compost is better than young compost in this respect. Over the longer term (>3 years) soil density decreases – increased aeration has been seen but there has only been a small number of studies. The majority of studies showed increased water-holding capacity and infiltration though this was in the longer term studies.

It was noted that many field studies did not provide a consistent picture of the details of the composts used e.g. ingredients, management of the composting process and quality parameters. If mineral fertilisers were added this was often not stated. Sometimes a good result was assumed if crop yields were not reduced. Studies referring to manure compost often involved the spreading of pure manure sometimes in large quantities leading to excessive enrichment - this was most common in America and Asia regions.

In general it was found that nitrogen leaching was reduced when compost was used compared to manure and soluble compound fertiliser (NPK). That said it is worth limiting compost applications to prevent too much nitrogen being added if the objective was the long term improvement of the soil. It is suggested that the phosphorus budget could be used to guide the level of application. The use of compost also tends to lead to fewer nitrates in crops and higher vitamin C levels have also been reported. In grass production mature compost leads to lower dry weight yields for the first three cuts then there was no difference thereafter – there was no difference in nitrogen mineralisation.

Compost produced in an aerobic process gives much more lasting effects than that produced anaerobically – this is linked with the increase in aerobic micro-organisms. Mature compost has been shown to reduce indices that measure metabolic stress in soil microbial communities. Young compost on the other hand increases degradation activity i.e. global metabolic activity. As an example of the effects of compost on macro-fauna the greatest biomass of earthworms was found in fields of wheat. Similar results have also been found in vegetable and apple systems when biodynamic compost and NPK were compared over an 8 year period. Compost can be antagonistic to nematodes – this has been demonstrated many times though a few projects have shown weak or non-existent effects. Several possible mechanisms have been identified.

Almost all pathogens are killed during the first phase (heating) of composting though the achievement of the necessary temperature and humidity is vital. It has been shown that the use of compost can protect against parasites and diseases but it must be good quality compost. There is considerable variability in compost quality so it is therefore essential to produce compost of constant quality using defined parameters. The mechanism of protection varies with the level of microbial activity in the compost, global nutrient supply and the improved physical properties of the soil that follows from the application of compost. This is also directly beneficial to plants and the improved health contributes to reduced fungal damage. A wide range of organisms has been isolated from composts. Interestingly it has also been shown that compost application can stimulate microbial activity even when it has been autoclaved. Composts vary in their effects when compared to other organic inputs e.g. pathogen stimulation increased following an application of straw compared to a compost application.

In terms of the compost itself it has been shown that the composition of the original mixture is less important than the degree of physical maturity of the compost. Differences in microbial population and nitrogen availability are also more important. Mature compost tends to be better than young compost but this only holds up to the point where microbial activity starts to decrease. The composting process can be tweaked with timed additions of materials such as lignin or chitin in various forms.

Within the other variations the effects of compost are generally proportional to the quantity administered. Clear long term effects arising from a regime of compost applications have been demonstrated by a number of studies but in general the positive aspects of more relevance are the nitrogen fertility that is supplied and the stimulation of soil microbial activity (or possibly the addition of compost micro-organisms). Much work has been done on extracts of compost and compost teas – many effects have been observed and some of these have been contradictory.

Fuchs, F. & Larbi, M. (2005) "Disease control with quality compost in pot and field trials" Conference Report.

This paper shows that some samples of compost had the potential to suppress fungal 'damping-off' diseases such as *Pythium ultimum* and *Rhizoctonia solani* in pot trials. This is not entirely germane to the review but similar effects were seen in follow up field trials, effects that were shown to persist for up to one year after compost application. That said the paper concludes that little is known about the longer term effects. These looked at *P. ultimum and R. solani* as above and also at *Blumeria graminis* (barley powdery mildew). Many of the aspects of this project fall outside the remit of the review but the following extract is a useful summary of the objectives of compost production:

"The management of the composting processes, in particular the oxygen supply, seems to be the most important factor affecting compost quality. This is also of major importance in compost storage (data not published). Compost quality is not stable, if it is stored the wrong way; compost is living and it can also die! Good quality compost can become toxic for the plant in few weeks, if it is not treated correctly, for example if its aeration is too poor. So, compost quality is the result of careful management throughout the production chain, from collection of the raw material to storage and application of the final product."

Litterick et al (2003) "Effects of manures and other organic wastes on soil processes and pest and disease interactions". This is a substantial report that essentially covers all the issues and topics of this review. More detailed extracts are reproduced as appendices to this review.

<u>Objective 2:</u> Review of effects of different composting processes on chemical and biological parameters in the finished compost or compost extract.

This is an area that does not impinge on the main topic but a number of points are worth quoting

- A number of farmers are moving into on-farm composting to both generate useful material for use on the farm and to generate additional cash-flow. This is often carried out under exemption because of the relatively small quantities involved. Catering waste cannot be composted on open sites as it is subject to the Waste Management Regulations.
- Defra should encourage the greater use of compost by farmers by:
    - Publishing soil maps showing where compost could benefit agricultural land
    - Providing advice on the agricultural and environmental benefits of compost
    - Describing the contribution that compost use can make to carbon sequestration
    - Extending farm environment schemes to cover the improvement of soil quality through the application of compost
- COMPOST is solid particulate material that is the result of composting, that has been sanitised and stabilised, and that confers beneficial effects when added to soil and/or used in conjunction with plants.
- COMPOSTING is the process of controlled biological decomposition of biodegradable material under managed conditions that are predominantly aerobic and that allow the development of thermophilic temperature as a result of biologically produced heat in order to achieve compost that is sanitary and stable.

<u>Objective 3:</u> Review of effects of un-composted materials, composts and manures on soil health and quality, soil fertility, crop development and nutrition.

General conclusions

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

Specific conclusions

- Manures and composts tend to increase soil organic matter content, reduce bulk density and increase porosity.
- Manures and composts generally improve aggregate stability
- Compost can have a significant impact on stabilising vulnerable soils against erosion
- As a result of increasing the soil organic matter content, composts and manures generally increase cation exchange capacity (CEC).
- Composts and manures can have a significant affect on soil pH.

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

Objective 4: A review of the effects of un-composted materials, composts, manures and compost extracts on beneficial microorganisms, pest and disease incidence and severity in organic agricultural and horticultural crops.

- At the time of writing there had been little or no application of un-composted plant materials, composts, manures or compost extracts/teas for the purpose of preventing or controlling pest or diseases in UK organic crops. In the US conventional and organic farmers are using such materials with some success.
- Organic farming generally benefits earthworms, and microbial numbers, processes and activities but not always. High soil diversity may help optimize nutrient cycling in the event of stresses due to adverse weather or soil conditions. It also has the potential for protection against plant pest and pathogens.
- There is increasing evidence of impact of un-composted materials, composts, manures and compost extracts on beneficial micro-organisms and P & D incidence and severity. The beneficial effects relate to the improvement of the biological fertility of soil because of the development of indigenous soil microbial populations. These largely determine soil quality and fertility, and thus plant establishment and productivity.
- Some measures that show improvement are not necessarily sustainable and they can often decline with time especially if the application producing the benefit is not sustained.
- 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 un-composted 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 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.

3. Analysis and Conclusions

Definitions (taken from Litterick et al, 2003)

Materials

- *Compost* is solid particulate material that is the result of composting, that has been sanitised and stabilised, and that confers beneficial effects when added to soil and/or used in conjunction with plants.
- *Composting* is a process of controlled biological decomposition of biodegradable materials under managed conditions that are predominantly aerobic, and that allow the thermophilic temperatures as a result of biologically produced heat, in order to achieve compost that sanitary and stable.
- *Green and wood waste* is vegetable waste from gardens and municipal parks, tree cuttings, branches, grass, leaves (with the exception of street sweepings), sawdust, wood chips, and other wood waste not treated with heavy metals or organic compounds.
- *Manure* is animal excrement which may contain large amounts of bedding.
- *Municipal Solid Waste (MSW)* is solid waste from households.
- *Sewage sludge* (also referred to as biosolids) is residual sludge from sewage plants treating domestic or urban waste water, and from septic tanks and other similar installations for the treatment of sewage.
- *Slurry* consists of dung, urine and water with only small amounts of bedding.

Processes

- *Passive composting* – this is the stacking of material (often manure or mixtures of manure and other organic materials) in heaps, windrows, etc. without turning until a measure of breakdown is achieved. Full breakdown can take up to 2 years and in the great majority of cases only partial breakdown is achieved before it is applied to the land. This essentially passive approach can be seen on a majority of organic farms thanks in part to an acceptance by certifying bodies that it achieves a sufficient degree of breakdown in 6 months for the material to be regarded as 'composted'.
- *Open windrow* – this is the most common approach to active on-farm composting adopted in the UK. Windrow are long narrow piles formed by front bucket machines (tall windrows) or specialised turning machines (low wide windrows). The composting period takes between 12 and 20 weeks with regular turning and re-mixing. There is no particular protocol for how frequently this is done nor is there any particular prescription for feedstock materials.
- *Aerated static pile* – this process is widely in a range of other countries but has not been adopted to any great extent in the UK. As the name implies a static heap is created but it is placed over a perforated pipe or plate – this allows air to naturally convect through the pile or it can be positively blown (or sucked) through the heap using a fan or compressor. The active composting phase can be complete in 3-5 weeks without turning provided that the air supply is sufficient and uniform.
- *In-vessel composting* – this is a group of composting systems that share the common feature of enclosed containers, bins, tunnels, etc. with a controlled air supply that can take the raw material through the active composting phase in around 14 days. Maturation is typically carried in piles or windrows. They generally give rise to higher quality and less variable composts but the costs currently rule out their regular use in organic agriculture.

- *Controlled Microbial Composting® (CMC®)* – this system is a development of the open windrow described above by the Luebke family in Austria. It is a covered windrow system that produces finished compost in 6-8 weeks (Diver, 2001). The feedstocks are carefully chosen to include a balance of well-structured materials with an overall C:N ratio of around 30. Typically this will include a proportion of nitrogen rich green material such as grass cuttings, crops wastes, etc. along with a proportion of carbon rich material such as shredded hedge prunings. A small amount of clay or clay rich soil can be added to assist the buffering of pH and labile nutrients, and a starter culture used to establish a desirable population of micro-organisms. The other key area of control is the close monitoring of temperature, moisture content and carbon dioxide production. The windrows are turned every time the internal temperature exceeds 60°C and maturity gauged using temperature and CO_2 emission. This is clearly a resource intensive system but it does give a relatively uniform product within a relatively short period of time.

The analysis will not cover all the above but the range of definitions has been included to avoid any confusion.

<u>Scope of the literature</u>. There is a large body of work but a lot is not relevant because:

- the compost has been supplemented with non-approved fertilisers
- not all urban waste composts are allowed
- manures from OF systems tend to have lower average nutrient contents than conventional materials
- manures are not always from systems acceptable to organic farming standards
- the old literature must be read with care especially with respect to municipal waste and sewage sludge; composting of raw materials has changed over the years.
- The basis on which comparisons are made can also be a problem as the criteria can vary considerably. (Litterick et al, 2003)

"It was noted that many field studies did not provide a consistent picture of the details of the composts used e.g. ingredients, management of the composting process and quality parameters. If mineral fertilisers were added this was often not stated. Sometimes a good result was assumed if crop yields were not reduced. Studies referring to manure compost often involved the spreading of pure manure sometimes in large quantities leading to excessive enrichment - this was most common in America and Asia regions" (Fuchs *et al*, 2004)

In reviewing a wide range of papers it was noticeable that when the use of compost was described there was no further definition of the origin, feedstock, composting method, age, biological properties and nutrient content of the material used. As an example a key paper describing the DOK trial refers to composted manure, rotted manure and stacked manure without further description (Mader et al, 2002). This is regrettable given the seminal nature of this particular project. A lot of good work has been done but because of a lack of rigour in defining the compost used conclusions for advisors and farmers must of necessity be somewhat tentative at times.

<u>Types of compost available to producers, and their qualities and properties.</u>

- *Uncomposted materials* are defined by Litterick et al (2003) as fresh plant residues including non-harvested plant parts such as cereal stubble, roots, leaves and rejected crop parts including root vegetables and fruits. These are clearly not composts but they can play a significant role in organic production systems both in providing nutrients and in the possible suppression of disease.

- *Green waste composts* are materials that are generated from green and wood waste as defined above. Increasing emphasis is being placed on the recycling of such materials in line with EU Directives and the responsibility for this is often placed on local authorities. In general much of the actual composting is carried out by private companies most of whom work to the PAS 100 standard (BSI, 2005) that lays down fairly strict parameters for the composting process, temperatures to be achieved and levels of contamination. These materials are generally acceptable for use in organic systems subject to the need being recognised by the Inspection Body. The quality and consistency of early examples of green waste compost (GWC) left much to be desired with often significant levels of glass and plastic along with a high percentage of uncomposted material in the form of wood fragments. Since PAS 100 has been introduced the quality has improved dramatically – contamination is very low and the final product is screened to remove larger fragments (these are recycled within the system). Moisture contents are relatively low and the material is easy to handle and spread. GWC can contain useful levels of phosphorus and potassium along with various trace elements. It also contains a potentially useful level of nitrogen but this is often so tightly bound that it does not benefit the crop. Salt levels and an alkaline pH are properties to be taken into account.
- *Manures* are mixtures of animal excrement and bedding that are either produced on farm or are imported from other holdings. Fresh manure can be used within an organic system but only if its use has been approved by the inspection body (Defra, 2006). Manure is a useful source of readily available nutrients but the levels can vary according to the type of livestock, the system, the livestock ration and the percentage of bedding that is included. Moisture contents can also vary and this can affect the ease of handling, and the time and effort required for spreading.
- *Stacked or stored manures* represent the most common form of bulky inputs used in organic systems. They are sometimes referred to as having been composted (Soil Association, 2006) though this is clearly a misnomer. In general terms such materials not fresh as they have been stored for a period that often exceeds six months and they have experienced some degree of breakdown that is partly aerobic and partly anaerobic. They are often stored in the open without a cover and they will lose nutrients through a combination of volatilisation and leaching. This can lead to higher moisture contents than even fresh manure so the effects can be less and the effort of spreading greater. Potassium and nitrogen are the nutrients most at risk of losses from the stack.
- *'Biodynamic' compost* describes compost made by biodynamic producers that uses a number of plant extracts to stimulate the process of breakdown. There are two approaches used in the production of this type of compost – one uses a static heap approach but in practice commercial operations tend to work with turning the heap using a tractor and bucket approach. Properly managed the process produces a very stable material though its nutrient content can vary as the feedstock can also vary.
- *CMC^R compost* is produced using a process patented by the Luebke family and involves the production of compost in covered windrows of fixed cross-section over a 6-8 week period. The feedstock is carefully chosen to include a balance of well structured materials with an overall C:N balance of around 30:1. The ingredients are mixed, water added if necessary and the windrows that are formed covered with a waterproof, breathable membrane – a proprietary starter culture is sometime added. The process involves the careful monitoring of carbon dioxide, moisture levels and temperature with the windrows being turned every time the temperature exceeds a certain level – turning can be quite frequent in the early stages of composting. This degree of control and monitoring results in compost that is uniform, consistent, friable and very easy to handle. Users of this material are convinced of the benefits for their systems. Moisture contents are relatively low, nutrient levels are fairly consistent and the availability of these nutrients to the crop is relatively slow release when compared to fresh manure.
- *Composts* are materials produced through a deliberate approach to mixing and turning to achieve a consistently aerobic regime. The term is used to describe aerobically produced composts that do

not fall into the above two categories. The type of feedstock can vary considerably from manure only to various combinations of plant material and animal manure. Properly managed these processes produce fairly consistent composts whose properties vary according to the feedstock used.

The role of composts in pest and disease suppression and, where shown, the mechanism for any effects.

Organic production must by its nature focus on preventative approaches so the role of composts and other bulky organic inputs in pest and disease prevention or control should be of considerable interest to producers. That said such use should not be seen as a substitute for techniques such as balanced rotations, resistant varieties, appropriate fertility management and mixed cropping.

The concept of soil health is seen as central to the management of organic production systems though it is rarely monitored in the UK. In a production system that has few effective and economic crop protection strategies the use of composts is seen as having potential in helping to improve and maintain soil health with consequent knock on effects for crop health. There is now a considerable body of evidence that confirms the impact of such materials on beneficial microorganisms, and pest and disease incidence and severity.

- *Effects of composts on pests.* The recorded literature relates almost exclusively to the control of plant parasitic nematodes. Municipal compost has been shown, for example, to reduce the level of root-knot nematodes in the roots of green peppers and tomatoes (Marull et al, 1997). In common with uncomposted plant residues and manures, the use of composts has been shown to have highly variable results including no effects or plain inconsistency. Much of the inconsistency can be attributed to differences in experimental technique, soil type, climate, farming system, compost feedstock and composting system. Much of the work has been carried out in warmer climates than the UK and in different soil types so it is unlikely that reliable systems will be developed for the UK without a considerable amount of work.
- *Effects of composts on diseases.* The suppressive activity of certain types of compost towards plant pathogens is well documented. The most successful and predictable effect has been seen in container production systems in the United States (e.g. Hoitink and Stone, 1997; Nelson and Craft, 1992). The effects of composts in suppressing diseases in field soil are being increasingly demonstrated though the understanding of the mechanisms is less well developed. Once again there is considerable inconsistency in the levels of disease suppression probably due to differences in soil types, experimental conditions and compost type. At the time of the Litterick review very little work had been published on the effects of compost on pest and disease control on organic farms in the UK and the position has not changed greatly since (Litterick, private comm.).

  Notwithstanding the above 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. One piece of work carried out on an organic farm showed that composted cattle manure significantly reduced the incidence of black scurf in potatoes caused by *Rhizoctonia solani* (Tsror [Lahkim] et al., 2001).

  Unfortunately the results from work done in tropical or Mediterranean climates in soil types not represented in the UK and on crops not grown in the UK cannot be directly applied especially when the results tend to be very variable. A considerable amount of work has been done on sewage sludge and municipal solid waste (as distinct from green waste) and some fairly clear effects have been demonstrated but it cannot be take into account as these amendments are prohibited under EU organic regulations and are likely to remain so for the foreseeable future. Some composted materials that have shown potential and that could be acceptable under current organic standards include the following:

Cattle manure	*Aphanomyces euteiches* in peas
	Fusarium oxysporum in nursery stock
	Rhizoctonia solani in potato and nursery stock
Cattle manure/leaves, pine bark	*Pythium ultimum* in cucumber
Poultry or chicken manure	*Fusarium oxysporum* in tomato
	Phytophthora cinnamoni in white lupin
	Rhizoctonia solani in tomato
Poultry manure/leaves	*Pythium ultimum* in nursery stock
Vegetable waste	*Phytophthora cinnamoni* in sweet basil
	Rhizoctonia solani in radish
Green waste	*Fusarium culmorum* in wheat
	Plasmodiophora brassicae in cabbage
	Phytophthora fragariae in strawberry
	Phytophthora nicotianae in pea
	Pythium myriotylum in tomato
Grape marc	*Pythium ultimum* in pea
	Sclerotina minor in lettuce
Hardwood bark	*Rhizoctonia solani* in cucumber
Bark	*Fusarium oxysporum* in sweet basil
	Pythium ultimum in chrysanthemum
Spent mushroom substrate	*Plasmodiophora brassicae* in cabbage

Some of the above also showed potential when used in combination with non-permitted materials. The literature also carries a significant number of references to the use and role of compost teas in the suppression or mitigation of plant diseases.

A considerable amount of work remains to be done in UK organic systems as examples such as the suppression of onion white rot using composted onion waste (Coventry *et* al., 2002) are the exception rather than the rule. This is a good example of the use of targeted materials and there must be potential for further work in this area. Research suggests that composts and compost extracts made from different feedstocks, or made using different techniques have widely differing properties in relation to beneficial and pathogenic organisms (Aryantha *et al*., 2000; de Brito Alvarez *et al*., 1995; www.soilfoodweb.com) .

- *Mechanisms for the activity of composts in the control of diseases*. Some broad conclusions on the potential for success of composts in the biological control of plant diseases can be drawn from the published body of evidence. As has been suggested elsewhere in this review the type of feedstock can be of considerable importance and there are suggestions that it is possible to 'tailor make' composts for particular crops and diseases (www.soilfoodweb.com) though the evidence for this is not yet widely published.

In general terms most composts that have been shown to have beneficial effects in disease suppression have been produced aerobically. Composts produced in an anaerobic system can contain a range of toxic end products and these can affect plant health adversely (Hoitink, 1980) though this can be mitigated if the material is incorporated well in advance of planting.

The maturity of the applied compost is extremely important in determining its activity against plant diseases. It has been shown that fresh organic matter does not support biocontrol even where it has been inoculated with specific disease suppressing organisms (De Ceuster *et al*., 1999). This has much to do with the fact that there are often high levels of free nutrients in fresh crop residues that can inhibit the activity of biocontrol organisms. Immature composts can contain toxic compounds that can affect the growth of crop plants and pre-dispose them to attack. On the other hand very mature composts that are highly humified cannot support the activity of biocontrol organisms. The aim is therefore to generate composts that are mature (i.e. have gone through a full cycle of decomposition and maturation) but have not been allowed to humify and lose much of the beneficial microbial population.

The chemical and physical properties of composts can also significantly affect their ability to influence both crop growth and health. The more important properties include cellulose and lignin content, electrical conductivity (soluble salt content), pH, the presence of toxic compounds, nitrogen content, and particle size. Air filled porosity is also important for container media (Hoitink *et al*, 1993). Toxic compounds are generally seen as having negative effects but composts based on tree bark can release natural fungicides that can control *Phytophthora* spp. The total salt content can influence the potential for disease control and where composts with high salt content are used it can be useful to apply them well in advance of planting to allow time for leaching to take place.

The aerobic composting process should, if managed correctly, generate high temperatures and these should ensure that no plant pathogens survive the process. Most plant pathogens are killed by 30 minutes exposure to 55^{o}C (Hoitink and Fahy, 1986) though some are less sensitive to heat. If there is a risk of the feedstock containing organisms such as tobacco mosaic virus and clubroot (*Plasmodiophora brassicae)* it should be treated in controlled in-vessel composting systems. Most beneficial micro-organisms are also killed during the high temperature phase of composting but some will remain in the outer cooler layers of the heap (Hoitink *et al*., 1997). The curing phase of compost production is the most important in terms of inducing disease suppressive properties of the finished material as the important organisms re-colonise the mass. Moisture content is the critical property (40-50%) if re-colonisation is to be successful. A wider range of organisms will re-colonise an open compost heap compared to in-vessel material (Kuter *et al.,* 1983).

<u>The direct and indirect effects on crop yields.</u>

There is a large body of work in this area covering the effects of composts and manures of yields of agricultural and horticultural crops but relatively little on the specific effect of composts on yields in organic systems. The literature tends to confirm the positive effects on crop yields that might be expected but as with other parameters the effects are never entirely clear cut. It is not always the case that yields are increased and there are a few references in the literature to depressed yields following compost applications. As has been mentioned elsewhere the feedstock for the compost would not always be approved by the organic standards (e.g. biosolids, sewage sludge, paper sludge, etc.).

It can also be difficult to separate the effects of compost additions from other fertility building strategies. This is one of the more significant problems in carrying out research on organic systems. The integrated nature of the system means that taking a reductionist approach and only looking at one variable may not give an accurate picture. The difficulties of assessing the effects of compost within such a system were demonstrated by the lack of any directly attributable effects of three years application of green waste compost on a UK organic farm because of other fertility management practices (HDRA, 2001).

Overall the main conclusion is that the fresher the material (i.e. manure) the greater the yield. Cooperbrand *et al* (2002) found that raw poultry manure applied at 9t/ha gave higher yields of corn compared with composts of 1, 4 and 15 months old applied at approximately 60t/ha. In one of the very few instances of an organically managed field trial corn yields were always higher when raw dairy manure was applied than when a compost of dairy manure and leaves was used (Reider *et al.*, 2000). The application rates were tailored to supply the same amount of nitrogen and this kind of approach can make it difficult to usefully compare different inputs and virtually impossible to draw generalised conclusions that can be applied in the field.

Effects on crop nutrition

Composts can clearly make a significant contribution to the nutrition of a wide range of crops but they have to be regarded in a different light compared to the effects of fresh manures. One of the key features of the composting process is the stabilisation of a significant proportion of the nitrogen content of the original feedstock – some is of course lost to volatilisation processes and leaching is always a risk in material exposed to the weather. There is an immediate fertiliser value that can be derived from the inorganic content and the readily mineralisable fraction. For a range of manure pellets this can involve the release of between 31% and 51% of total N content in the first 3 months after application (Yan *et al.*, 2002).

The longer term aspect of nitrogen mineralisation also needs to be considered and work has been done on the development of decay series that attempt to predict the proportion of added N that becomes available over subsequent years (Klausner *et al.*, 1994). There are a number of models of nutrient cycling that take into account the losses in storage, handling and applications of manures but few if any references to composts can be found in them (e.g. EU-Rotate_N – http://go.warwick.ac.uk/eurotaten). Out of 24 organic matter inputs only one was described as compost and that was called somewhat enigmatically, bio-waste compost. There is a need for clarification in this area given the increasing use of green waste composts, materials that have been shown to have significant levels of strongly bound N. Is this eventually released or does it stay locked up? In general terms soils receiving regular inputs of organic matter have greater labile C pools and greater N supplying ability than soils receiving mineral amendments (Gunapala and Scow, 1998).

A further aspect of nitrogen release in the soil is the matching of supply and demand for N. A good understanding of the dynamics of N release from a range of materials and the demands of crops is required if this is to be achieved. Fresh manures tend to release N more rapidly and at higher levels than composted manures (Cooperbrand *et al.*, 2002), characteristics that may be put to good use for certain short term, high demand crops. The mixing of fresh and composted material has the potential to address crop needs (Handayanto *et al.*, 1997) but this is probably not practicable on a farm scale.

A significant problem that arises from the use of composts of various kinds to supply crop nitrogen is the possibility of the over-supply of phosphorus. The N:P ratio of most manures and composts in smaller than the N:P uptake ratio of most crops (Eghball, 2002). This may not be a problem in the short term but sustained high applications of composts could lead in time to excess levels of phosphorus in the soil with implications for crop health and the leaching of P into the environment. Fuchs *et al* (2004) suggest that it may be prudent to programme applications on the basis of P content especially if the objective is long term soil improvement. If a soil is deficient in P then it might be worth considering the mixing of rock phosphate in with the organic matter as organic acids could aid dissolution of the rock (Litterick *et al.*, 2003).

In contrast it has been found that potassium in organic wastes tends to be as available as it is in mineral fertilisers (Wen *et al.*, 1997). This means that it can be at risk of leaching during the composting process and the resulting material can thus be a poor source of K (Barker, 1997). If it can be conserved through careful management of the process then it can add useful quantities of K to the soil (e.g. Wen *et al.*, 1997). It is also worth noting that compost made from grass and straw can contain approximately twice the K content of chicken manure (Eklind *et al.*, 1998), a fact that could be useful in stockless systems.

Detectable and measurable effects on crop quality (an appropriate definition of quality will be required).

There is very little to report in this area though there has been some work done on dry matter levels, nitrogen contents, etc. and the suggestion is that for these parameters fresh manure has a more marked effect. It has been very difficult to track down any specific references to quality though of course there are measures such as those applying to grain. These few references tend to relate to materials such as slurries and sewage sludge rather than compost so it is impossible to draw any conclusions, positive or negative in respect of compost. The ability of organic materials to supply a balance of mineral elements could potentially improve product quality but it has yet to be clearly demonstrated.

The effects of compost applications on soil biology

Soil biology is by its nature a very complex subject as reference to any decent soil science text will confirm. All farming systems will have a significant effect on the diversity and sheer numbers of soil organisms (microflora, microfauna, mesofauna, macrofauna, etc.) but it is arguably only organic farming systems that seek to have positive effects. Such systems are (or should be) focused on efficient nutrient cycling through the maintenance of a large and diverse population of soil organisms (Litterick *et al.*, 2003). Organic farming practices have generally been shown to have beneficial effects on earthworm populations (Pfiffner and Mader, 1997) and on soil microbial numbers, processes and activities (Shepherd *et al.*, 2000).

Positive effects are not always demonstrated particularly in respect of pasture systems where little or no difference between organic and conventional systems is seen – this is ascribed to the fact that both systems accumulate organic matter and this has positive effects on both sides. It is therefore not possible to draw a blanket conclusion that all organic systems have positive effects and conventional systems negative effects on aspects of soil biology. The concept of soil health is central to organic farming but it is rarely assessed or monitored in the UK. It is a very complex concept that sees the soil as a dynamic living organism but it is possible to gain useful guidance by monitoring earthworm count and soil respiration. Test kits are available in the US and can now be obtained in the UK (www.solvita.co.uk). These have proved useful in demonstrating the effects of management decisions on soil health (Ditzler and Tugel, 2002).

Microbial processes and properties largely determine soil quality and fertility – these then impact on plant establishment and productivity. A wide range of beneficial effects on soil microbial properties have been demonstrated and these can improve the biological fertility of the soil. It should also be noted that the effects are not always beneficial and can be negative on occasion. As noted elsewhere in this review researchers are working with materials such as fresh manures and sewage sludge – these either lie outside the scope of this review or would not be allowed in organic systems.

The effects of compost applications on soil organic matter levels, and the implications for carbon sequestration.

As a general rule the benefits to soil organic matter levels from applications of composts are positive but short to medium effects are not always seen especially where there is a high background level of soil organic matter or where the soils are very light and well aerated. Single applications are unlikely to have a lasting effect – regular applications over time are required as in the long term experiments at Rothamsted where increases from 0.87% to 2% have been recorded over a 25 year period (Johnston *et al.*, 1989). This was achieved using composted FYM – fresh FYM gave a lower increase over the same time period (0.87% to 1.46%).

There is a clear and increasing interest in managing soil carbon sequestration as a key strategy in meeting the requirements of the Kyoto protocol. The potential for the use of compost and other applied organic inputs to make a significant contribution is there but a quick review of a number of strategies suggests that techniques such as cover crops, biomass crops, no-till systems and forestation are often seen as more important. The fact that increases in soil organic matter have been recorded in a wide range of soils and systems (McConnell *et al.*,1993) suggest that perhaps this should be taken more seriously as a means of carbon sequestration. The demonstration by Eghball (2002) that 36% of carbon applied in compost remained in the soil after four years compared to 25% of carbon applied in manure suggests that composts could have a greater role to play in this area.

The most appropriate situations for the use of compost as opposed to fresh manure. (This has a particular relevance in the production of ready to eat horticultural crops)

This review has been focused on compost but in the course of assessing the available literature it has been clear that the use of manures also has many beneficial effects. It is not often the case that farmers and growers have a choice between the use of compost and manure. It should also be acknowledged that what many farmers regard as compost is actually stacked manure – there is no way it can be regarded as compost according the definitions listed earlier in the review.

As a general summary, manures can be regarded as having higher available nutrient levels especially nitrogen and an organic component that is more susceptible to breakdown. This can make it more useful in sustaining crops that have a relatively high nutrient demand. The following table has been adapted from Ott (1996) by Litterick *et al.*, (2003) and illustrates the kind of factors that should be taken into account when considering whether to stack or fully compost available manure:

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

These are clearly generalised conclusions and would not all apply in the same situation. They nevertheless provide a useful summary of the kind of issues to be considered when planning the fertility management of a cropping rotation. The use of plant based composts that are found in stockless systems would clearly have more in common with the composted FYM than with the stacked FYM

Conclusions and recommendations

It is clear from the this review and the reviews and papers it has considered that the use of compost in the sense of the full definition has considerable potential for improving soil chemical and physical properties. These effects are not always demonstrated in every piece of work but taken overall we can see a range of useful benefits. It is also the case that some benefits that are often assumed do not manifest themselves – the use of compost to provide significant quantities of available nitrogen is a case in point.

The conclusions from the main Litterick review can be seen elsewhere in this review but the remainder of this section will focus on those aspects that are of practical use and/or benefit to producers and advisors. This will be an attempt to distil those aspects that are of clear benefit from the wide body of work that has been carried out and also to provide some guidance on what could be seen as negative aspects of compost use.

- Many producers believe that they are producing composts when all they are doing is stacking manure uncovered for a period of time with perhaps a single turn of the heap. There is nothing wrong with this approach in principle but it should be recognised that stacking such material in the open carries a considerable risk of nutrient losses through leaching and/or volatilisation. This in turn carries considerable implications for environmental pollution not to mention the loss of useful nutrients (K and N) from the system. It has the very real benefit of being cheap and to some extent it optimises the recycling of nutrients (those that are not lost) around the farm. For these reasons it is unlikely to be replaced by other methods on many farms.

Recommendation: **in situations where stacking is seen as the easiest and cheapest way of managing manure, consideration should be given to covering the heaps with breathable covers such as Gore-Tex® or to the use of redundant farm buildings where these are available.**

- The use of compost is likely to provide useful amounts of potassium and phosphorus but it is clear from the work that has been reviewed that its contribution to available nitrogen status is moderate at best. It is possible to provide sufficient nitrogen for an annual crop but the quantities of compost required risk the over-application of phosphorus and potassium.
- Management of the composting process is crucial to maintaining the potassium status of the final product. Potassium does not get bound to any great extent during the composting process and is therefore always present in a soluble form. The key to preserving useful quantities of potassium, often a limiting factor in organic systems, is the prevention of leaching and again the use of covers should be considered to prevent losses via this route. It should also be noted that compost made with a combination of grass and straw can contain twice the potassium of chicken manure.
- A case has been made in the literature for calculating compost inputs on the basis of the impact on P status to avoid the build up of excess phosphorus over time. On the other hand the mixing of rock phosphate with the compost feedstock is likely to increase its solubility and hence phosphorus availability in situations where available soil P is very low. This kind of approach is only possible where the compost is made on-farm i.e. where there is total control over both process and materials.

Recommendation: **In an ideal world producers should take complete control of the composting process and the feedstock used. The process should be managed to minimise potassium losses, and rock phosphate included in the feedstock where soil phosphorus status is**

particularly low. It is clear that a clear and accurate assessment of soil nutrient status should be available if the best judgements are to be made in terms of quantities to be applied (to prevent excessive phosphorus accumulation for example). Stockless cropping operations should seriously consider the use of fresh grass and straw based composts as a way of addressing the potential potassium deficits that can build up in such systems in the absence of animal manures.

<u>Recommendation:</u> Producers that buy in compost in the form of green waste compost or other types of compost acceptable under the organic standards can gain some assurance of product nature and consistency from the fact that the great majority of materials are produced under the PAS 100 standard. That said analyses of the materials concerned should be examined to see if the pH, nutrient status, etc. are appropriate to the soil type and cropping system concerned.

- A minority of producers are using a more disciplined approach to on-farm composting. Some are working to biodynamic principles, some are using the CMC® approach and some have developed their own approach working from first principles. In the first two examples the requirements are laid out in some detail and close observance leads to the production of a consistent and easily handled product. In the *ad hoc* category good results can also be obtained by paying attention to carbon:nitrogen ratios, regular turning of the heaps or windrows and ensuring that the feedstock is finely shredded where possible.
- The requirements for initial preparation, regular turning and close attention to monitoring all add significantly to the cost of production. In general terms the practitioners consider this to be money well spent as they are convinced of the benefits and the advantages over stacked manures. Many claims have been made for such composts especially the CMC derived materials and it should be understood that these have not all been confirmed through research, past or current.
- It is however quite clear that compost can confer a range of benefits on soils and cropping systems. These include positive effects on a range of beneficial micro-organisms, soil physical properties and as seen above the nutrient status of the soil. Some of these benefits are clear cut, others less easy to demonstrate. It is also clear the variable nature of the materials described as compost in the range of projects and trials covered by the various review means that many of the positive benefits cannot always be demonstrated and there are a number of papers that refer to negative effects on soil properties, crop yields, etc.
- A further conclusion to be drawn from the large body of work is that while most positive effects can be demonstrated following one application of compost it is the regular and continuing applications year on year that bring lasting change to the system. This particularly true when considering the effects on soil organic matter levels, cation exchange capacity, structural stability, etc.

<u>Overall Conclusion.</u> There is clear potential in the use of compost in organic systems to improve the overall condition of the soil, its biology and its ability to supply nutrients to the crops grown. It should not be assumed however that all composts will do the same thing and an assumption that because a material has been produced by a composting process it will be good should be avoided. Much will depend on what has been composted, how the process has been managed and what the objective of the application is.

An absolute key is being able to use material that is consistent in its properties (physical, chemical and biological) and is able to provide maximum benefit to the production system. Clearly compost produced on-farm working to a clearly defined system such as CMC is likely to deliver on both of these issues though it will of course also require consistency in the feedstock.

If the objective is to deliver nitrogen fertility to a demanding crop then compost of whatever kind should not be the material of choice.

In a mixed organic farming system where livestock enterprises are important the use of un-composted or un-aerated materials can be appropriate especially where replacing nutrients removed by forage cuts. In most other systems a degree of treatment including stacking should be seen as advantageous providing steps are taken to minimise losses during the storage and breakdown phases.

Advisors and producers need to look at a range of factors in the system before deciding on the most beneficial approach in the management of bulky organic materials. Soil type and basic fertility profile of the soil should be key factors – where the soil is light, relatively nutrient poor and of low organic matter status compost or fully composted manure should be the material of choice in helping to build up the soil over the medium to long term. It may also be the case that some additional fertility in the form of stacked manure and/or proprietary materials may be required in the short term.

If working with a soil of medium to heavy texture that is well structured and has a good basic fertility profile then the approach taken can be more flexible. In these situations manures are likely to give the greatest benefit though compost use should be considered in the interest of future cropping plans. All of this must be taken in the overall context of the standards that "The fertility and the biological activity of the soil must be maintained or increased, in the first instance, by:

(a) cultivation of legumes, green manures or deep-rooting plants in an appropriate multi-annual rotation programme

(b) incorporation of livestock manures from organic livestock production in accordance with the provisions and within the restrictions of paragraph 7.1 of part B of this Annex

(c) incorporation of other organic material, composted or not, from holdings producing according to the rules of these Standards." (Defra, 2006)

The other key aspect surrounding decisions relating to the use of compost is that of cost and there should be a commitment to examining the cost-benefit analyses of various approaches. This can be quite fraught as controlled windrow systems require high capital and running costs that may not necessarily be reflected in absolute yield increase or tangible improvements in crop quality. Supporters of such systems (e.g. CMC) remain absolutely convinced that the production and use of such compost brings a range of benefits to the whole farming system that do not necessarily affect the bottom line at least in the short to medium term.

In summary the use of compost has the potential to improve almost all relevant soil properties, its effectiveness is closely related to its consistency but achieving that consistency through highly controlled on-farm systems may not necessarily justify the costs of production.

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See note above on references in section 2

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5. Appendix

This is a more detailed coverage of one of the sections of the key paper that has informed this review

Litterick et al (2003) “Effects of manures and other organic wastes on soil processes and pest and disease interactions”.

<u>Objective 3:</u> Review of effects of un-composted materials, composts and manures on soil health and quality, soil fertility, crop development and nutrition.

3.1.1 Soil health definition based on living organism concept.

3.1.2 Soil fertility in organic farming carries several definitions, several of which are based on the ability to supply nutrients to the crop. It can also be viewed as an ecosystem concept – this is more appropriate to organic farming. OF relies on soil organic matter management to enhance the chemical, biological and physical properties of the soil. Thus the management of the soil will control nutrient supply to the crop though it is noted that organic horticulture systems can rely on purchased manures.

3.1.3 OF systems rely on strategic management such as rotations and their specific design. Yields can vary widely - 50%-95% in European systems yet US system can be closer. Soils need to be managed to synchronise N mineralisation with maximum N demand. A review of 29 studies involving compost application showed 10 with higher crop dry matter, 7 with higher mineral content and 7 with higher vitamin C. Spring cereal protein levels can be higher. OF needs improved yields and quality – variety breeding can clearly help but improved management of manures and composts has the potential to improve crop nutrition.

3.1.4 Scope of the literature. There is a large body of work but a lot is not relevant.

(a) the compost has been supplemented with non-approved fertilisers
(b) not all urban waste composts are allowed
(c) manures from OF systems tend to have lower average nutrient contents than conventional materials
(d) manures are not always from systems acceptable to OF standards
(e) the old literature must be read with care especially with respect to municipal waste and sewage sludge; composting of raw materials has changed over the years.
(f) The basis on which comparisons are made can also be a problem as the criteria can vary considerably.

3.2 Effect on soil health, quality and fertility

3.2.1 *Soil organic matter*. A number of studies have shown that SOM can be increased significantly by regular inputs of composts and manures – effects can be more significant in sandy soils. There can be implications for carbon sequestration – one study showed 25% of carbon from manure remaining in the soil after 4 years while compost applications led to 36% remaining in the same time.

3.2.2 *Biological properties* – these are covered under Objective 4

3.2.3 *Chemical properties*

3.2.3.1 pH In general the results were mixed with increases, decreases and no effect. The outcomes tended to depend on the compost pH and the pH of the soil to which the compost was applied. In some cases manure can substitute for lime applications.

3.2.3.2 Nitrogen Incorporated plant residues can be important in OF though the N content can very hugely (35kgN/ha for cereals compared to over 150kgN/ha for some vegetable residues). The incorporation of N rich, low C:N ratio residues of fresh plant material, manures or composts will lead to rapid mineralisation and a large rise in soil mineral N. This will occur at C:N ratios below 15 while ratios above this level will generally lead to immobilisation

3.2.3.3 Phosphorus Soil P will increase with continued application of organic manures and composts. This can lead to problems in soils already high in P. There is a case for limiting applications in these situations by not exceeding extractable P levels of 70mg/l. The mixing of rock phosphate with manures and composts is likely to increase P solubility while lime added to poultry manure will have the opposite effect. Unlike N P availability increases with successive applications regardless of the maturity of the applied material. Experimental design can make it difficult to assess the relative merits of different composts on soil nutrients.

3.2.3.4 Potassium K remains in water soluble forms in composts – composting does not affect availability but applications can influence soil K and plant uptake. There is a danger of leaching during the composting process. Composts derived from grass and straw can have twice the K of poultry manure.

3.2.3.5 Other nutrients Composts can also provide non-NPK nutrients. There is a view that some positive yield effects come from the supply of Ca and Mg, and composted manure has been shown to increase soil Ca in at least one study.

3.2.3.6 Electrical conductivity This is essentially a measure of salt concentration in the soil solution and it has been shown to increase with increased manure/compost application rates. It is unlikely that the types of composts under consideration will have any detrimental effect (unlike sewage sludge) but it needs to be borne in mind.

3.2.3.7 CEC The Cation Exchange Capacity of a soil describes its ability to retain cations on soil colloids – it is important in the retaining of nutrients and their subsequent release for plant uptake. Soil organic matter is important (along with clay minerals) in maintaining CEC. In general it is improved by applying compost at normal agronomic rates though there are exceptions.

3.2.4 *Physical properties*. The effects of organic matter additions on soil physical properties vary according to a wide range of parameters including climate, soil type, and type of OM addition among others. Quality is more important than quantity in terms of beneficial effects on aggregate stability. It can be the case that more OM is needed to improve structure than is needed for the growing crop.

3.2.4.1 Water holding capacity and porosity In general terms the application of OM in the form of compost will improve soil WHC either directly through its own ability to absorb water in unstructured soils or indirectly through moderation of those soil properties that influence WHC e.g. pore size and continuity. Similar effects can be seen for soil porosity – this can increase in direct relation to compost application rates.

3.2.4.2 Bulk density/penetration resistance Mixed effects on soil bulk density have been seen – in general it decreases as might be expected but sometimes the effects on soil properties can increase it. Reduced soil penetration resistance is also commonly reported – this has also been seen in subsoil measurements.

3.2.4.3 Aggregate stability. Much work has been done in this area but it is difficult to compare results because of different methods and variation in the presentation of application rates. Beneficial effects are often seen though differences between composted and non-composted materials are not always seen. The effects on well-structured soils are likely to be limited and the general effects can be short-lived because of the natural decay of organic matter. Regular applications will however have long term effects. Micro-aggregation has been shown to be improved by the addition of humates extracted from green waste compost – the status of such materials within the organic standards is unclear.

3.3 Potential environmental impacts

3.3.1 Nitrate Leaching There are few if any clear conclusions here – N content of applied materials is not a reliable indicator for N leaching potential though there is a suggestion that high C materials will reduce it. The timing of application can be more important than the type of material applied. There has been little reporting of robust work on the leaching potential of composted and fresh materials. What there is suggests that composted material gives rise to lower leaching rates.

3.3.2 Runoff and erosion. In unstable soils OM applications will reduce the erosion potential and composted material has the greater effect. There is a risk of P runoff from applied manure – losses can vary between 1.9 and 17.1% of applied P. Inappropriate application times can contribute to the problem. In general runoff was less from composts than manures.

3.3.3 Gaseous losses Field applied manures contribute 10% of all ammonia emissions across Europe. More work has been carried out on slurry than solid manures and little attention has been paid to the effects of composting the manures. It has been shown however that losses from manures stored anaerobically are higher than material kept in an aerobic state. Prompt incorporation will of course make a difference. Annual nitrous oxide emissions have been shown to increase with manure rate though little work has been done to compare the effects of different materials in the field.

3.3.4 Human pathogens. There is a perceived risk of pathogens contamination organic food as result of the use of animal manures. The use of fresh manure is prevented by the standards (is it?) and composting/anaerobic digestion of manure/slurry have been shown to reduce pathogen viability. None of the claims of higher risk has been substantiated though work to ensure the lowest microbiological risk possible should continue. This is borne out by the fact that E. Coli (0157) is excreted by as much as 15.7% cattle in the UK. The risk is clearly lower in municipal plant based composts.

3.3.5 Potentially toxic elements (PTE's). These are potentially a greater problem in urban wastes but can also occur in animal manures where metals are present in the diet (copper in pig and poultry feeds). There can be implications for the food chain as well as toxicity issues for the final consumer. Much depends on application rate (often too high in many pieces of work) and soil type (adsorption properties). Regulation controls the levels in sewage sludge and more recently in municipal green waste compost (PAS 100). Total heavy metal content in soils will increase in proportion to applied compost or manure but little work has been done on the effects on extractable levels.

3.4 Crop development and nutrition

3.4.1 Yield There is a lot of work done in this area though very little on yield in organic farming systems. Many studies show a positive effect on yield but there are also plenty of reports of neutral and negative effects. Different composts can have different effects in the same crop. The effects of applied nutrients in composts can sometimes make more of a difference in the following crop so a longer term approach may be more appropriate. Compost maturity can affect yield with less mature materials having the greatest effect – the effects on following crops can be difficult to separate from other aspects of the system.

3.4.2 Crop nutrition Applied organic materials carry proportions of nutrients that can be easily determined through analysis. The proportion of readily mineralised nutrients can also be determined though this does not always match field performance. There are also differences between manure based materials and plant based composts. Information on the effects of composts and manures in organic systems is limited though again manures tend to contribute more immediate N than composts. A further danger is the potential to over-supply

P in an attempt to supply sufficient N. P uptake can vary with maturity of the compost while K in organic materials is as available as it is in mineral fertilisers. Few studies have focused on minor nutrients – where there has been done the suggestion is that fresh materials contribute more Ca and Mg than mature composts.

3.4.3 Product quality. There are very few reports on the effects of composts on quality though it is expected that organic materials have the ability to supply a balance of mineral elements and thus improve quality. There is also little information on the effects on differential development of crop maturity, or above ground and below ground development.

3.4.4 Plant health (see Objective 4)

3.5 **Tools and models for compost application** Improving soil fertility in organic farming through the use of composts relies on improved understanding of the effects of feedstocks, composting and application methods on soil fertility and also on improved technology transfer of the results of research. 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 can often under-estimate the nutrient values of organic materials so analyses can be useful. There is also a need for user-friendly tools that can predict nutrient transformations from added organic materials to meet crop demand and avoid N losses by leaching and volatilisation, and P losses from runoff. There are a number of such tools that have been developed for conventional systems – some are being further developed for organic systems.

3.6 **Systems aspects** There are a number of specific points that need to be considered when dealing with organic systems such as the rotational aspects of the system. Nitrogen fixation can be depressed by N application whether this is mineral or organic. Nutrient management must be understood, planned and managed over longer periods than for a single crop or growing season. It may be that different materials will suit different soils and crops – low N composts could supply P & K to low N demand crops. Herbage composts with high K could be useful in stockless systems or on sandy soils. It may be appropriate to determine application rates on the basis of the P & K in the available material. Balancing P & K offtake in organic systems with acceptable P & K inputs is a priority in organic systems. The use of nutrient budgets should help to illustrate these issues.

3.7 Conclusions

3.7.1 General conclusions

3.7.1.1 Caution must be exercised in generalising on the effects of composts on manures on soil health, fertility and crop nutrition due both to the variable nature of composts, and their interactions with climatic, edaphic and crop properties.

3.7.1.2 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.

3.7.1.3 While general principles are likely to be applicable in both conventional and organic systems, caution must be exercised in drawing comparisons between use of composts and manures in organic and conventional farming. This is due to the different composition of manures from organic farms and the restrictions of the organic standards but also due to the different rotations and cropping patterns which exist in the two systems.

3.7.1.4 There is a need to address manure and compost applications in the context of farming systems rather than individual crops.

3.7.2 Specific conclusions

3.7.2.1 Manures and composts tend to increase soil organic matter content, reduce bulk density and increase porosity.

3.7.2.2 Manures and composts generally improve aggregate stability

3.7.2.3 Compost can have a significant impact on stabilising vulnerable soils against erosion

3.7.2.4 As a result of increasing the soil organic matter content, composts and manures generally increase cation exchange capacity (CEC).

3.7.2.5 Composts and manures can have a significant affect on soil pH.

3.7.2.6 Composts are generally of little value as N fertilisers compared with fresh manures.

3.7.2.7 N availability from composts and manures is dependent on C/N ratio. High C/N ratio materials can immobilise N. C/N ratio can potentially be used to manipulate N supply in the field.

3.7.2.8 Application of composts at rates that are likely to produce a significant N response will generally oversupply P and K.

3.7.2.9 P availability is generally similar from raw and composted materials, responses are usually proportional to total P applied.

3.7.2.10 Compost is often a poor source of K due to leaching loss during composting.

3.7.2.11 Composting of organic wastes does not appear to affect K availability.

3.7.2.12 Gaseous nitrogen losses tend to be lower from composted than fresh organic materials, but management options to minimise these losses need further development.

3.7.2.13 There is a need to investigate trade-off's between different gaseous and leaching forms of pollutants following compost application. This should include methane and carbon dioxide.

3.7.2.14 There is little information on pathogen persistence and movement in soils/water following spreading.

3.7.2.15 Gaseous and leaching losses from the use of compost need to be assessed in the context of the farming system rather than for individual crops.

3.7.2.16 Manures and composts have the potential to improve and crop nutrition. They may be particularly beneficial in terms of minor elements.

3.7.2.17 There is very little information available on the effects of compost on product quality in field grown crops.

3.7.2.18 There is a need to adapt models of nutrient cycling and loss for use in organic systems.