Project Title:	Composting of onion and other vegetable wastes, with particular reference to control of *Allium* white rot.
Project Number:	Horticulture LINK Project CSA 4862 and HDC FV 219
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Location of project:	HRI-Wellesbourne, HRI-Kirton and Grower sites.
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Intellectual property rights are invested in the Consortium of Horticulture LINK Project CSA 4862.

Consortium members:

Bedfordshire Growers Limited

Fenmarc Produce Limited

G's Marketing Limited

Goldwood (Moulton) Limited

Horticultural Development Council

Horticulture Research International

JJ Barker Limited

CONTENTS

PRACTICAL SECTION FOR GROWERS

Commercial Benefits of the Project

This project has developed a commercial-scale controlled composting process for onion and other vegetable wastes. The composted waste is produced with minimal run-off and odour pollution, and is free of the pathogens, *Sclerotium cepivorum* and *Olpidium brassicae*, and pests commonly found in vegetable waste. In addition, the composted waste has a fertiliser value and *Allium* white rot control activity. Application of the composted waste to white rot infested land has potential to:

- Reduce or eliminate landfill and associated costs
- Reduce fungicide usage and the length of crop rotations currently needed to avoid build-up of the white rot pathogen
- Return onion growing land currently infested with *Allium* white rot to onion production
- By these actions, address the DEFRA priorities of promoting sustainability in UK Agriculture

Background and Objectives

Loss of the best onion growing soils due to white rot infestation has forced onion production into areas with less suitable conditions for growing high quality onions, increasing the need for transport to centralised packing and storage sites. The accumulation of onion waste in these areas poses a risk of infestation and contamination from crop pests and pathogens, as well as a source of odour and run-off pollution. Landfill disposal of such waste is becoming increasingly expensive. One possible solution is for composted onion waste to be returned to the field providing it is pathogen free. Previous on-farm experiments (Oldershaw, pers. comm.) have indicated that windrow composted onion waste applied to fields may eliminate white rot sclerotia from infested soil. Onion waste contains compounds capable of inducing the sclerotia of the white rot pathogen, *Sclerotium cepivorum*, to germinate, and germinated sclerotia are unable to survive in the absence of a living host. Composted onion waste could, therefore, provide a means to clean-up white rot infested land.

The **objectives** of this project were to:

1. Develop controlled composting systems for onion and onion-based vegetable wastes in the laboratory

2. Determine conditions required to eliminate pathogens and pests from laboratory-scale composting systems

3. Determine conditions required to retain white rot sclerotia stimulant activity and the effect of composted vegetable waste on sclerotia viability

4. Quantify the effects of controlled composted onion-based wastes on white rot control, sclerotia survival and onion growth in pot tests

5. Carry out large-scale (20 tonne) controlled composting of onion and onion-based vegetable wastes in bulk tunnels

6. Quantify the effects of rate, storage and timing of application of composts produced in bulk tunnels under controlled conditions on white rot control, sclerotia survival and onion growth in field tests

Summary of Results and Conclusions

Objective 1

Development of controlled composting systems for onion and onion-based vegetable wastes in the laboratory

Two categories of bulb onion waste, wet (peelings, crushed whole onions) and dry (shale, tops) were identified. Composting each category of waste alone in small-scale flask experiments was either impractical, in terms of the bulk of material involved, or produced large volumes of run-off and unpleasant odours. A wet: dry onion waste mixture prepared to an 80% moisture content, with urea added at 4 g/kg waste, was found to be optimal in minimising run-off and odours produced during composting at 50 ºC for 7 days (Table A). This mixture also reflected the amounts of wastes produced by the industrial partners. Mixtures of *Brassica* and carrot waste with onion shale, and spring onion waste with straw, prepared to the same moisture content and conditions of incubation gave similar results.

Table A

Effect of bulb onion waste composition on run-off and odour produced during composting at 50 ºC for 7 days in 2 L flasks

Dry Matter Content (%)	Ratio of Wet: Dry Waste	Comments
13	1:0	Odour very strong especially in the first few days Considerable run-off (50-100 ml)
16	16:1	No unpleasant odours 1-20 ml run-off
20	10:1	No unpleasant odours Very little run-off (*c.* 1 ml)

Composted onion peelings, *Brassica* and carrot waste each mixed with onion shale were found to contain nitrogen, phosphorus and potassium and hence have potential fertiliser value (Table B). In addition, the low pH of the composted onion waste may render it suitable as a peat alternative.

Table B

Analysis of vegetable waste composted with onion shale for 7 days at 50 ºC. Values for nitrogen, phosphorus and potassium are percentage based on fresh weight.

Sample	Total Nitrogen	Phosphorus	Potassium
Onion peelings	0.57	0.08	0.65
Broccoli + cauliflower waste	0.79	0.09	1.40
Whole carrots	0.46	0.10	1.05

Objective 2

Determination of conditions required to eliminate pathogens and pests from laboratory-scale composting systems

Sclerotia of *S. cepivorum* were incubated in flasks containing onion waste at a number of temperatures for 7 days. As the incubation temperature was increased, percentage germination of the sclerotia retrieved from the waste decreased (Figure A). All sclerotia were destroyed at temperatures of 48 ºC and above.

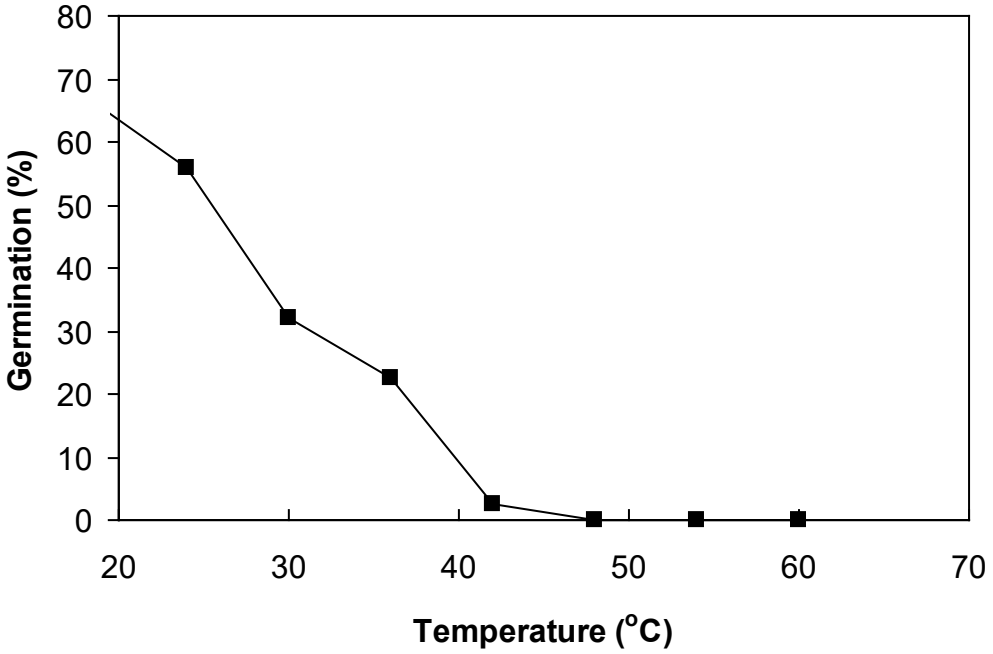

Figure A

Effect of temperature on germination (%) of sclerotia incubated in onion waste for 7 days. Values are the mean of 3 replicates.

Similar flask-scale experiments were conducted at 50 ºC over 7 days with onion waste inoculated with propagules of the pathogens *Olpidium brassicae* and *Fusarium oxysporum*. These conditions destroyed all propagules of *O. brassicae* and reduced the viability of *F. oxysporum*. The nematode, *Steinernema feltiae* and 5 day old onion fly larvae (*Delia antiqua*) were also destroyed by these conditions.

Objective 3

Determination of conditions required to retain white rot sclerotia stimulant activity and the effect of composted vegetable waste on sclerotia viability

Onion waste composted at two different temperatures (42 ºC and 54 ºC) for 3 and 7 days was analysed for the presence of the white rot sclerotia germination stimulant, di-n-propyl disulphide. The higher temperature and longer incubation period had no detrimental effect on the level of this compound in the onion waste compared with that found in the lower temperature produced composts.

The effect of composted vegetable waste in sandy loam and silt soils on the viability of sclerotia of *S. cepivorum* in glasshouse pot tests was found to be dependent on length of exposure and the amount of waste present. In general, the longer the sclerotia were in contact with the waste and the higher the rate of incorporation, the greater the reduction in viability. The composted vegetable waste was also shown to influence the viability of sclerotia in peat soil although there was no relationship with duration of exposure.

Objective 4

Quantification of the effects of controlled composted onion-based wastes on white rot control, sclerotia survival and onion growth in pot tests

The effect of composted onion waste incorporated into peat, silt and sandy loam soils at a rate of 50% on control of AWR in pots differed between soil types. Good consistent control of the disease was achieved in peat soil; no disease control was observed in silt soil; and disease control in sandy loam soil was variable (Figure B).

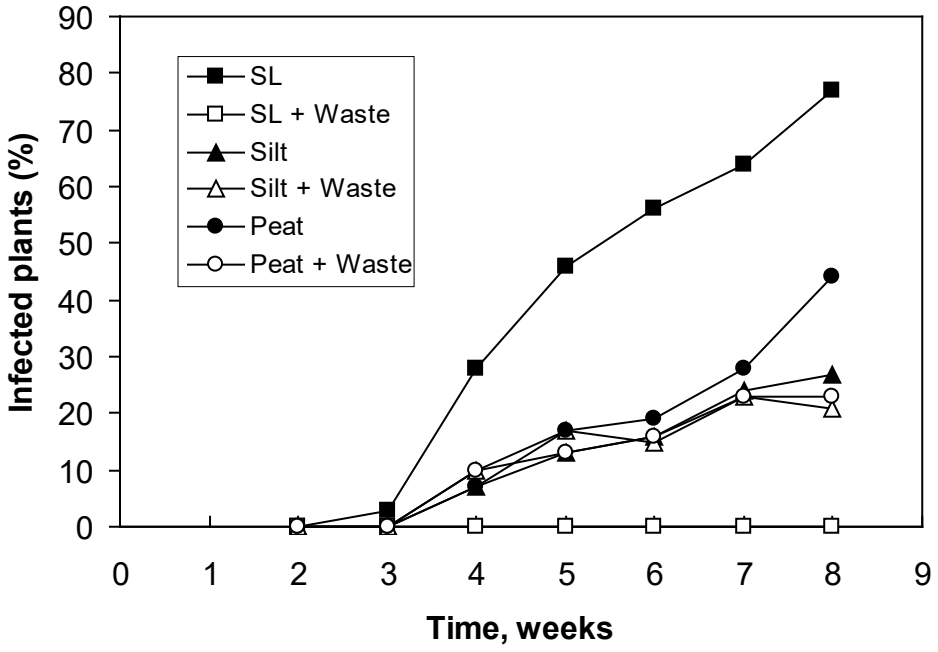

Figure B

Onion plants (%) infected with *Allium* white rot in 3 soil types (sandy loam (SL), silt and peat) containing composted onion waste (waste) (50% incorporation rate) inoculated with 3 sclerotia/g of mixture. Values are the mean of 50 replicate pots.

The presence of composted onion waste (6 months old) incorporated at a 50% rate into peat, silt and sandy loam soils in pots was phytotoxic to onion seedlings. Seed germination and seedling growth were reduced in compost amended pots compared with that in soil alone.

Objective 5

Large-scale (20 tonne) controlled composting of onion and onion-based vegetable wastes in bulk tunnels

On the basis of the results from the small-scale flask experiments and pot bioassays, various mixtures of vegetable wastes (onion peelings + shale; sweetcorn + broccoli + onion shale; salad onion + straw), prepared to an 80% moisture content (85% for salad onion mixture), were composted for 7 days at 50 ^{o}C in 6 or 20 tonne capacity bulk tunnels. No unpleasant odours and limited run-off were produced during composting. In addition, the volume of the waste mixtures generally halved during the composting period.

Objective 6

Quantification of the effects of rate, storage and timing of application of composts produced in bulk tunnels under controlled conditions on white rot control, sclerotia survival and onion growth in field tests

Bulk tunnel batches of composted salad onion waste were prepared for a commercial field trial in Kent, and composted wet/dry onion waste batches were prepared for a field trial at HRI-Kirton and commercial field trials in Bedfordshire and Cambridgeshire. The field application rates of the composted waste were: Kent = 16%; HRI-Kirton = 50%; Bedfordshire = 27%; and Cambridgeshire = 54%. Composted waste stored for 2-5 months was also used in the field trial at HRI-Kirton.

Commercial Field Trials – The presence of the composted vegetable waste had no effect on the viability of sclerotia retrieved from the three field trials, although generally more soft sclerotia (non viable) were retrieved from the test plots than the control plots. Recovery of sclerotia from the test plots was significantly lower than from the control plots. No AWR was recorded in bulb onions in either the control or test plots at the Bedfordshire and Cambridgeshire sites. At the field trial in Kent, a level of disease control was achieved in salad onions with the composted onion waste incorporation, with fewer plants infected with AWR recorded in the test plot than in the control plot. No visible signs of phytotoxicity were observed in the plants grown in the compost amended plots, although the weights of the control plants from the Bedfordshire and Cambridgeshire sites were slightly heavier than those from the compost amended plots. The presence of the salad onion waste in the field trial at Kent however increased the growth of overwintered onions by about 40%.

Field Trial at HRI-Kirton - Composted onion waste applied and incorporated at a 50% rate was not detrimental to onion emergence providing there was sufficient delay between application and planting, otherwise emergence was better in fresh compost than in stored. Control of AWR with composted onion waste differed with onion variety and the condition of the compost. Fresh onion waste compost applied and incorporated at a 50% rate either 1 or 9 months prior to planting Rijnsburger sets was as effective as Folicur (a.i. tebuconazole) in controlling AWR throughout the growing

season (Figure C). Treatment with Folicur however was shown to be more effective than the compost treatments in controlling disease on Sturon variety sets (Figure C). There was some evidence of phytotoxicity in the field trial at harvest with onion yield reduced slightly in the presence of the composted onion waste compared with the untreated controls. This problem could possibly be overcome by having a longer delay between compost application and planting.

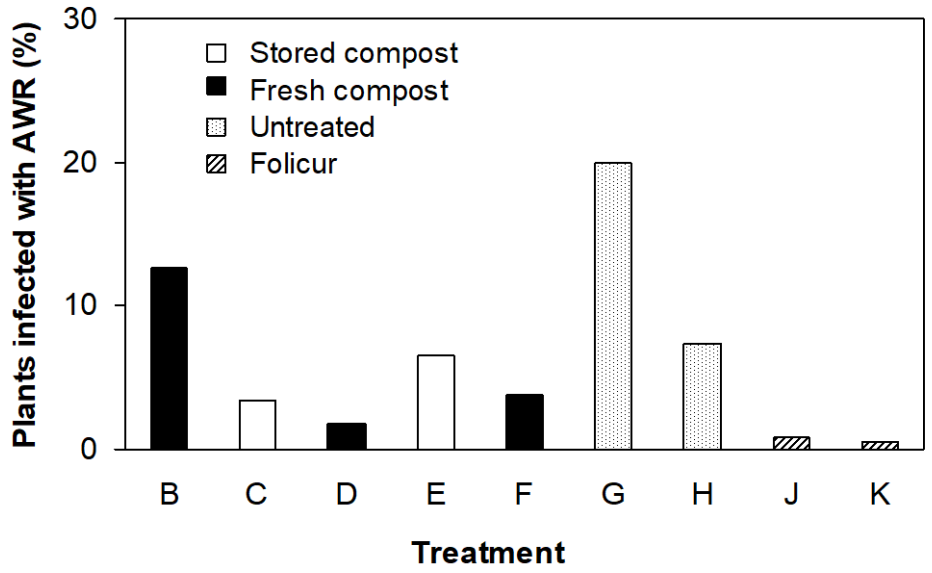

Figure C
Plants infected with *Allium* white rot (%) in the various treatments at harvest
Sturon = B, G and J. Rijnsburger = C, D, E, F, H and K.

Action Points for Growers

- Vegetable waste mixtures with a moisture content of 80% are optimal to minimise run-off produced during composting
- Onion shale and straw are suitable materials to mix with wet wastes to reduce their moisture content
- A 10:1 ratio of wet: dry wastes will produce a waste mixture with a moisture content of *c.* 80%
- The waste requires aeration (either frequent turning in a windrow system or a ventilation system in a bulk tunnel) to avoid unpleasant odours during composting

For vegetable waste to be safely returned to the field after composting without contaminating the land, it must be pathogen and pest free.

- Waste composted for 7 days at 50 ºC under controlled conditions will ensure pathogens such as *S. cepivorum* and *O. brassicae*, and pests such as onion fly larvae and nematodes are destroyed.

Composted onion waste applied and incorporated to land at a 50% rate:

- Reduces viability of sclerotia of *S. cepivorum*
- Is not detrimental to onion emergence providing there is sufficient delay between compost application and onion planting. Onion crops should not be planted on land in the same year of compost application.
- Is as effective as Folicur in controlling AWR throughout the growing season. Freshly made compost performs better than stored.

Anticipated Practical and Financial Benefits

- An environmentally acceptable controlled composting system for onion and other vegetable wastes which produces minimal odour and run-off.
- The compost produced is white rot free and has major reductions in other pathogens and pests.
- The compost has the ability to reduce white rot disease when applied to white rot infested soil. The compost can be stored and repeated application may enhance the effect.
- The compost has a significant fertiliser value.
- Composting reduces the bulk of the waste and enables the compost to be applied to land rather than going to landfill, saving haulage and landfill costs. In addition, the availability of landfill sites is decreasing and future legislation may prevent disposal of green wastes in landfill. The composting of vegetable wastes and their return to land hence provides an alternative to landfill for their disposal which will be required in the future.
- The relative value of constructing controlled composting facilities needs to be addressed by the individual consortium members.

MILESTONES

Year 1

Primary Milestones

1.1 Complete physical and chemical analysis of separated wastes supplied by Industrial partners.

1.2 Determine the temperature and aeration conditions and waste composition to achieve appropriate rates of degradation and control of odour and run-off pollutants during composting in the laboratory.

2.1 Determine the temperature and aeration conditions and waste composition to achieve elimination of white rot sclerotia and propagules of *Olpidium* and *Fusarium*, nematodes and onion fly larvae during composting in the laboratory.

3.1 Determine sclerotial germination activity in composts produced in 1.2 and 2.1 by monitoring volatiles using GC-MS/Electronic nose and by incorporating composts at various rates into soil containing sclerotia and monitoring survival after 3 months – short-term viability.

Year 2

Primary Milestones

3.2 Determine sclerotial germination activity of composts produced in 2.1 by monitoring volatiles using GC-MS/Electronic nose and by incorporating composts at various rates into soil containing sclerotia and monitoring survival for up to 12 months – long-term viability.

4.2 Assess optimised composts from 3.1 and 3.2 for effects on onion growth, white rot incidence and sclerotial survival in pot-based tests.

5.2 Produce composts in 20 tonne bulk composting tunnels at HRI-Wellesbourne for use in field trials and monitor survival of pathogens and pests.

6.2 Set up field trials to determine effect of early application and storage of compost before application on onion growth, white rot disease and sclerotial survival at HRI-Kirton and in commercial field sites.

Year 3

Primary Milestones

5.4 Produce composts in 20 tonne bulk composting tunnels at HRI-Wellesbourne for use in field trials and monitor survival of pathogens and pests during bulk tunnel composting.

6.4 Set up field trials to determine the effect of rates of application, storage and initial waste composition of compost produced in bulk composting tunnels in field experiments on onion growth, white rot disease and sclerotial survival in uninfested and white rot-infested soil (HRI-Kirton) and in commercial field sites. Monitor and harvest all field trials.

6.6 Preparation of industry-based manual on composting and utilisation of onion and other vegetable wastes.

Progress against Milestones: All Milestones have been completed.

SCIENCE SECTION

Introduction

The loss of the best onion growing soils due to white rot infestation has forced onion production into areas with less suitable soils and climate for growing high quality onions. These disease-free areas are becoming more remote from established centralised packing and storage sites, increasing the need for road haulage with concomitant cost penalties and environmental pollution.

The accumulation of vegetable crop wastes in growing areas and processing centres poses a risk of potential infestation and contamination from crop pests and pathogens, as well as a source of odour and run-off pollution. Figures obtained from several major vegetable co-operatives and packers indicate that onions and root vegetables account for over 30,000 tonnes of waste annually in the UK, with landfill disposal costs of over £500K. With the introduction of landfill taxes, currently at £16/tonnne, these costs are set to rise. The option of disposal of vegetable wastes as animal feed is decreasing with a reduction in herds due to problems associated with BSE. One possible solution is for waste to be returned to the field, since composted vegetable waste is a potential fertiliser and soil conditioner. In the case of onions, the waste may also provide a novel control solution for *Allium* white rot (AWR), since it contains compounds capable of inducing the sclerotia of the pathogen *Sclerotium cepivorum* to germinate, and germinated sclerotia are unable to survive in the absence of a living host. Previous on-farm experiments (R. Oldershaw, pers. comm.) have indicated that windrow composted onion waste applied to fields may eliminate white rot sclerotia from infested soil. Application of composts which stimulate white rot sclerotia germination in infested soils would be an environmentally friendly and sustainable method of disease control allowing the possibility of organic onion production in the future. There is consumer and retailer pressure to reduce the use of pesticides and less reliance would need to be placed on chemical treatments to control white rot. In addition, there is currently only one fungicide, Folicur (a.i. tebuconazole), approved for the control of AWR in the UK, which was not available when the project commenced (January 1999).

Composted vegetable wastes from production and processing centres can be disposed of on to fields. Waste can be composted in either an uncontrolled or controlled manner. Uncontrolled composting in static or turned windrows can result in a significant reduction in the volume of the waste but, due to the variable temperatures throughout the composting material, does not ensure all pests and pathogens are destroyed, thus limiting the ease of disposal of the processed compost. The uncontrolled nature of windrow composting means that while considerable odour and run-off pollutants are produced, useful compounds such as *S. cepivorum* sclerotia germination stimulants present in onion waste may be destroyed. Controlled composting of waste materials in aerated bulk composting tunnels can overcome these problems. Waste for composting is housed on a slatted floor above a plenum through which a controlled flow of air is blown. This ensures the waste is kept aerobic and reduces unpleasant odours. In addition, a uniform temperature is maintained throughout the waste and hence all pathogens and pests with a thermal death point below the waste temperature are destroyed.

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Materials and Methods

Bench-scale Development and Assessment of a Controlled Composting System for Vegetable Wastes (Milestones 1.1, 1.2)

Analysis of Separated Wastes Supplied by Industrial Partners

Vegetable waste (bulb onion, *Brassica* and carrot) collected from five of the industrial partners (Elgro Limited, Goldwood (Moulton) Limited, Fenmarc Produce Limited, G's Marketing Limited and Bedfordshire Growers Limited) at 3 different times of the year was analysed for total nitrogen, dry matter and ash content. These initial determinations provided the information required to calculate the moisture and nitrogen contents of the waste mixtures prepared for composting. Salad onion waste produced by one of the industrial partners (JJ Barker Limited) was similarly analysed to determine its dry matter content.

Composting of Vegetable Waste

Small-scale flask experiments were conducted using various mixtures of dry (shale or onion tops) and wet (peelings or chopped whole onions) onion waste prepared to different moisture contents to identify the optimum waste composition to achieve minimal run-off and control of odour. The onion waste mixtures (with 4 g urea/kg waste added to achieve a nitrogen content of 1.4% of dry matter) were composted in 2 litre "Quickfit" multiadapter flasks immersed in thermostatically controlled waterbaths. The waste mixtures (*c.* 700 g) were placed on a perforated stainless steel platform within each flask and the flasks immersed in the waterbaths such that the water level was above the level of the enclosed waste. Each flask was connected to ancillary equipment providing independent aeration of the waste. The waste was aerated for 2 minutes in every 30 minutes at a flow rate of 250 ml/min controlled by means of flow meters. The temperature of the waste in the flasks was monitored with Squirrel multipoint temperature loggers (Grant Instruments Limited, Cambridge, UK). Ammonia, carbon dioxide and oxygen levels in the flasks were monitored using a Draeger Gas Detector (Dragerwerk, Lubeck, Germany) with appropriate sample tubes (CH20501 (NH_3), CH31401 (CO_2), 8101811 (CO_2) and 6728081 (O_2), respectively). The waste was incubated at 50 ^oC for 7 days after which any run-off was measured and weight loss, dry matter and ash contents determined as described previously [Noble & Gaze, 1994].

Similar experiments were conducted using *Brassica* and carrot waste prepared to an 80% moisture content (6 parts wet waste: 1 part dry waste by weight) which was found to be optimal for the onion waste with respect to minimising run-off. Onion shale served as the dry material for each of the *Brassica* and carrot waste mixtures. These wastes were chopped to *c.* 3 cm pieces to fit in the flasks and encourage degradation. Mixtures of salad onion waste and straw prepared to various moisture contents (80%, 85% and 90%) were composted under similar conditions.

To ascertain the potential fertiliser value of the various waste mixtures, their conductivity and pH was measured and a sample of composted onion, *Brassica* and carrot waste analysed for nitrogen (no urea added), phosphorus and potassium.

Elimination of Pathogens from Infested Vegetable Waste (Milestone 2.1)

The pathogens of interest in this study were *Sclerotium cepivorum*, *Olpidium brassicae* and *Fusarium oxysporum*, organisms commonly found in vegetable waste. The source and maintenance of each of these pathogens is described below:

***S. cepivorum* -** Sclerotia from two 14 day old Potato Dextrose Agar (PDA) plate cultures (Kirton strain) were removed using a sterile spatula and added to 10 ml sterile distilled water (SDW). The sclerotia suspension was homogenised for 30 seconds then added to 500 ml SDW. This suspension (100 ml) was used to inoculate mushroom spawn bags (Van Leer Packaging Systems Limited, Dorset). Each bag contained 1920 g sand (Dried Silica Sand, Hepworth Minerals and Chemicals Limited, Cheshire), 80 g flaked maize (Midland Shires Farmers Limited, Worcester) which had been ground in a blender to <1 mm diameter particle size, and 175 ml water, which had been autoclaved at 121 ºC for 15 min. The bags were heat sealed and incubated for 6 weeks at 20 ºC. To harvest the sclerotia, water was added to the sand-maize-sclerotia mixes and the sclerotia decanted into a 212 µm mesh size sieve. The sclerotia were left to dry in a laminar flow cabinet then mixed to 50% with sand, enclosed within fine polyester mesh* bags (150 µm pore size) (Lockertex Limited, Warrington) and buried outside in soil *c*. 150 mm deep for 12 weeks to condition the sclerotia. After this period the sclerotia were retrieved as previously described. This provided a stock of conditioned sclerotia for future experiments.

***** This polyester mesh was used to prepare bags for sclerotial burial in all other experiments.

O. brassicae – Resting spores of *O. brassicae* were provided by J. Walsh and J. Bambridge, HRI, Wellesbourne.

F. oxysporum – SDW was added to 5 day old plate cultures of *F. oxysporum* provided by J. Carder and C. Grant, HRI, Wellesbourne to suspend the microconidia. The microconidia were counted and 2 ml of a 10^6 conidial suspension added to 10 g of sterile talc in a 50 ml Duran bottle. The inoculated talc was incubated at room temperature (*c*. 22 ºC) for 6 weeks during which time chlamydospores of *F. oxysporum* formed. This served as a stock of the organism.

Effect of Temperature and Aeration on the Survival of Pathogens

S. cepivorum

Conditioned sclerotia (100) and 2 g of onion waste were enclosed within fine polyester mesh bags (prepared from 140 mm diameter circles and closed with a tie wrap), placed in the centre of onion waste mixtures in flasks and incubated at various temperatures for up to 7 days. To investigate the effect of volatiles released from the composting onion waste on the viability of the sclerotia without subjecting them to the composting temperatures, similar bags of sclerotia were incubated in the nozzles in the flask lids. There were 3 replicate flasks per treatment each incubated in a separate waterbath. At intervals throughout the 7 day incubation, bags of sclerotia were removed from the composting flasks. Sclerotia were washed from the onion waste with water, collected on a 212 µm mesh size sieve, and retrieved using forceps under a binocular microscope. The sclerotia were surface sterilised in sodium

hypochlorite (>5% but <16% available chlorine, Hays Chemical Distribution Limited, Leeds) for 1.5 minutes using a hand-held pipette with a modified 10 ml tip which held the sclerotia on a polyester mesh platform [Williams, Whipps & Cooke, 1998]. The sclerotia were rinsed in SDW four times and plated on to PDA containing 20 mgl^{-1} chlortetracycline. Viability of the sclerotia was assessed as percentage germination after 14 days.

To investigate the response of sclerotia of *S. cepivorum* to temperature, similar flasks containing bags of onion waste infested with sclerotia were incubated at temperatures ranging from 18-60 ºC with 6 ºC intervals for up to 7 days. There were three replicate flasks per treatment with each replicate flask incubated in a separate waterbath. One bag of sclerotia was removed from each composting flask after 3 and 7 days and sclerotia retrieved, surface sterilised and assessed for viability as previously described.

On the basis of the information obtained using the onion waste, subsequent experiments involving *S. cepivorum* and composting the *Brassica* and carrot waste were conducted at 50 ºC over 7 days.

O. brassicae

One ml of water containing 3000 resting spores of *O. brassicae* was used to inoculate 30 g of autoclaved sharp sand (Silvaperl Sharp Sand, William Sinclair Horticulture Limited). The sand was allowed to air dry before enclosing it within a fine polyester mesh bag. Mesh bags containing the inoculated sand were placed in the centre of onion waste mixtures in flasks and incubated for 7 days at 50 ºC. After 7 days incubation the sand containing the *O. brassicae* resting spores was retrieved and mixed with a further 30 g of sand. Seven day old lettuce seedlings (*Lactuca sativa* L., cultivar Little Gem) grown in vermiculite at 15 ºC were transplanted into P40 modules containing the sand, watered with NFT solution every second day, and monitored for 8 weeks for symptoms of *O. brassicae* infection. Controls consisted of inoculated sand incubated on the bench and uninoculated sand.

F. oxysporum

Talc (0.1 g) inoculated with *F. oxysporum* was mixed with 10 g of 2 mm sieved Wellesbourne soil, enclosed within fine polyester mesh bags and incubated in onion waste in flasks for 7 days at 40 ºC and 50 ºC. After 7 days the inoculated soil was removed from the flasks and plated on to Komada medium selective for *F. oxysporum* (see Appendix I for media preparation details).

Elimination of Pests from Infested Vegetable Waste (Milestone 2.1)

Similar flask-scale experiments to those involving the pathogens were undertaken with onion fly larvae and nematodes. Five day old onion fly larvae (*Delia antiqua*), enclosed within polyester mesh bags containing onion waste, were placed in the centre of onion waste mixtures in flasks and incubated for 7 days at 50 ºC. The nematode, *Steinernema feltiae* (test organism) was similarly added to flasks and subjected to the same conditions.

Sclerotia Stimulant Activity of Composted Vegetable Waste (Milestones 3.1, 3.2)

To determine the effect of composting temperature on the sclerotial germination stimulant di-n-propyl disulphide (dpds) and other sulphurous compounds present in onions, a mixture of onion shale and peelings prepared to an 80% moisture content was incubated at 42 ºC and 54 ºC for 3 and 7 days. There were three replicate flasks per treatment and each replicate flask was incubated in a separate waterbath. A freeze-dried sample of each of the composted waste mixtures produced was analysed for sulphur-containing compounds using Gas Chromatography – Mass Spectrometry (GC-MS).

The composted waste produced was also used to set up a glasshouse pot bioassay (glasshouse heating set points were 14 ºC day, 12 ºC night; ventilation set points were 18 ºC day, 16 ºC night). Various rates of the raw and composted waste (1%, 10% and 50% w/w) were incorporated into sieved sandy loam soil (Bedfordshire) containing 20% v/v vermiculite to prevent clumping of the soil. Square pots (70 x 70 x 80 [deep] mm Optipots (LBG Limited, Evesham)) were filled with the soil-waste mixtures (220 g) and 4 polyester mesh bags (2 cm x 2 cm) each containing 2 g of 50:50 (w/w) sand: soil and 100 sclerotia buried in the pots. Pots were watered from the bottom to maintain a moisture content of *c.* 40% w/w. There were 3 replicate pots per treatment arranged as a split-plot design. The mesh bags were retrieved at one month intervals for 3 months and then at 6 months and the sclerotia assessed for their viability (% soft and % germination) as previously described.

Similar pot bioassays were set up with *Brassica* (white cabbage, cauliflower and broccoli florets) and carrot (whole or crushed wet) wastes composted with onion shale at 50 ºC for 7 days in sandy loam, silt (Lincolnshire) and peat (Cambridgeshire) soils to determine the effect of raw and composted vegetable waste incorporation on the short and long term viability of sclerotia in these soils. For comparison, onion peelings with shale, and no waste were used. The 3 soil types were from onion growing areas in the UK.

Temperature Effects on Glasshouse Studies

At the PMG meeting in January 2001 the point was raised that temperatures in the glasshouse, particularly during the summer months, may not reflect those in the field. The pot bioassay results reported in Years 1 and 2 were obtained under glasshouse conditions. It was therefore suggested that comparative pot based tests in the glasshouse and field would provide useful information on any effect of temperature.

Composted onion waste (incubated at 50 ºC for 7 days) was incorporated into sieved sandy loam, silt and peat soil at a 50% rate. Pots (70 mm x 70 mm x 80 mm) were filled with the soil-vegetable waste mixtures (220 g) and polyester mesh bags (2 cm x 2 cm) each containing 2 g of 50:50 (w/w) sand: soil and 100 sclerotia buried in the pots. Identical experiments were set up in the glasshouse and in the quarantine field at HRI-Wellesbourne, and the air temperature recorded in both environments. There were 3 replicate pots per treatment arranged in a randomised block design. The mesh bags were retrieved at 1 month intervals for 3 months, and then at 6 and 9 months, and the sclerotia assessed for their viability (% soft and % germination).

Control of *Allium* White Rot with Composted Onion Waste (Milestone 4.2)

Onion waste composted for 7 days at 50 ºC was incorporated at a 50% rate (w/w) into 3 soil types (sandy loam, silt and peat). The soil-waste mixtures were inoculated with 3 conditioned sclerotia (Kirton isolate) per g of mixture and left in a glasshouse for 2 months. This standing period was to simulate the period left between compost application and sowing in the field. After 2 months, pots (70 mm x 70 mm x 80 mm) were filled with the soil-waste mixtures (220 g) and two onion seeds (*Allium cepa*, cultivar White Lisbon) sown per pot (subsequently thinned to one per pot) (Seed Pot Bioassay 1). There were 50 replicates per treatment for each soil type arranged in 5 blocks. Control pots with the waste mixtures and soils alone with no sclerotia added were included for comparison (30 replicates per treatment). The pots were assessed weekly for 8 weeks for the presence of white rot, scored as dead plants. This pot bioassay was repeated using seeds (Seed Pot Bioassay 2) and then twice again using 4 week old onion seedlings which were transplanted into the pots (Seedling Pot Bioassays 1 and 2). Onion seedlings (4 week old) transplanted into uninoculated soil-waste mixtures were also assessed for 4 weeks for any signs of phytotoxicity resulting from the waste incorporation. The initial length of the onion seedlings at transplanting was 21.1 cm (mean of 30 plants).

Larger-scale Controlled Composting of Vegetable Waste in Bulk Tunnels (Milestones 5.2, 5.4)

On the basis of the results obtained from the flask bench-scale experiments, salad onion, bulb onion and sweetcorn, broccoli + onion shale waste was composted in 6 or 20 tonne capacity bulk tunnels at HRI-Wellesbourne for use in field trials to assess the effect of compost application on white rot control.

1. Salad Onion Waste

   On the basis of the results from the small-scale composting flask experiments, salad onion waste was mixed with straw in a 9:1 ratio to give an 85% moisture content. Urea was added at 4 kg/tonne of mixture and the waste composted for 7 days at 50 ºC.

2. Bulb Onion Waste

   Onion peelings or crushed whole bulbs were mixed with shale in a 10:1 ratio to give an 80% moisture content. Urea was added and the waste mixture composted as described for the salad onion waste. Five bulk tunnel loads of this type of waste mixture (wastes supplied by Goldwood (Moulton) Limited, Bedfordshire Growers Limited and G's Marketing Limited) were composted for 1 week during the period July 2000 – November 2000.

3. Sweetcorn + Broccoli Waste

   Sweetcorn + broccoli waste was mixed with onion shale in a 2:1 ratio (64% moisture content). Urea was added to the waste mixture, which was composted as described for the salad onion waste.

Field Trials (Milestones 5.2, 5.4, 6.2, 6.4)

On the basis of the pot bioassay results, a 50% incorporation rate of the waste was chosen for the field trial work. The composted waste was applied as a 75 mm (3 inch) layer and disked in to 150 mm (6 inches) at each of the field trial sites. (The actual rate of composted waste applied varied slightly from the target 50% due to variations in the size of commercial site plots and volumes of compost produced).

1. Salad Onion Waste

   The composted waste produced in the bulk tunnels was applied fresh, at a depth of 24 mm (16%, assuming 150 mm disk depth), to land naturally infested with white rot belonging to one of the industrial partners (JJ Barker Limited) in July 2000. Polyester mesh bags containing sclerotia, similar to those used in the pot bioassays, were buried in control and treated areas within the planting depth.

   Crop 1
   Salad onions were sown (variety Ramrod) in September 2000 and a sample of the buried sclerotia assessed in November for any effect of the compost application. Retrieved sclerotia were assessed in terms of percentage soft and percentage germination as previously described. A further sample of sclerotia was assessed at harvest (May 2001) and 100 plants from both the control (no waste) and test (waste applied) plots assessed for the presence of white rot.

   Crop 2
   Salad onions were sown (variety Ramrod) in May 2001 and the incidence of white rot recorded at harvest (August) as described for crop 1.

2. Bulb Onion Waste

   The composted bulb onion waste produced in the bulk tunnels was applied to 2 field sites:

   (a) HRI-Kirton

   Land (sandy silt loam soil) at HRI-Kirton was artificially infested with sclerotia of *S. cepivorum* (0.4 g/m^2). Stored (two month old) and freshly made composted onion waste was applied at a depth of 75 mm (50%, assuming 150 mm disk depth) to plots (1.8 m wide x 10 m long) of the white rot infested land in August 2000, and bags of sclerotia buried as described previously. A Folicur dipped sets treatment (0.5% Folicur solution for 20 minutes) was included for comparison. Control plots had no compost applied. There were six replicate plots per treatment. A sample of sclerotia from the plots was assessed for viability in October 2000. Onion sets were planted in April (variety Sturon) and May 2001 (variety Rijnsburger) and further samples of sclerotia assessed for the effect of the composted waste on viability in May and August. Emergence of sets in four x 1 m lengths within each plot was recorded over a 2-4 week period. White rot assessments were made throughout the growing season (in four x 1 m lengths within each plot) and onion yield recorded at harvest (August). At harvest, the onions were

graded into 3 size categories: bulbs <40 mm, 40-60 mm and >60 mm in size, and the presence of *Allium* white rot and other rots recorded.

Stored (5 month old) and freshly made compost was applied to other plots in April 2001 and sets (variety Rijnsburger) planted in May. There were six replicate plots per treatment. A sample of sclerotia from the plots was assessed for viability in June, August and September. Similar to the crop planted in April and May described above, white rot assessments were made throughout the growing season and onion yield recorded at harvest (September). The bulbs were graded according to size, and the presence of *Allium* white rot and other rots recorded as described previously.

(b) Bedfordshire Growers Limited

Composted onion waste was applied fresh, to a depth of 40.5 mm (27%, assuming 150 mm disk depth), to land naturally infested with white rot (Bedfordshire – sandy loam soil) in January 2001. Bags of sclerotia were buried within the planting depth as described previously. Onion sets (variety Red Baron) were planted in April and sclerotia from the field site sampled in May and July and the effect of waste application on sclerotia viability assessed in terms of percentage soft and percentage germination of retrieved sclerotia. A white rot assessment was made on the crop at harvest (August).

(c) Goldwood (Moulton) Limited

The field trial on this site was cancelled due to bad weather conditions which prevented application of the composted waste to the land.

3. Sweetcorn, Broccoli + Onion Shale Waste

Composted sweetcorn, broccoli + onion shale waste was applied fresh, to a depth of 81 mm (54%, assuming 150 mm disk depth), to land naturally infested with white rot (Cambridgeshire – peat soil) belonging to one of the industrial partners (G's Marketing Limited) in January 2001, and bags of sclerotia buried as described previously. Onion sets (variety Sherpa) were planted in April and sclerotia were sampled from the field site in June and July and assessed for viability. A white rot assessment was made on the crop at harvest (August).

Results

Bench-scale Development and Assessment of a Controlled Composting System for Vegetable Wastes (Milestones 1.1, 1.2)

Analysis of Separated Wastes Supplied by Industrial Partners

The bulb onion waste produced by the industrial partners varied but all produced dry onion waste (shale or onion tops) with the majority also producing some type of wet waste (peelings or whole onions). The dry matter content of the wastes was above 70% for the dry wastes and below 16% for the wet wastes (Table 1). The dry wastes were found to have a higher ash content than the wet wastes but lower total nitrogen. The salad onion waste was found to have a slightly higher moisture content (93%) than the bulb onion waste (85-90%).

Table 1
Dry matter (DM), ash and total nitrogen (N) (%) content of onion waste. Each value is the mean of two replicates.

Company	Waste	DM (%)	Ash (% of DM)	Total N (% of DM)
Elgro Ltd	(i) shale	79.5	10.8	0.68
	(ii) peelings	14.4	4.5	1.00
	(iii) whole onions	15.4	4.6	1.37
Goldwood (Moulton) Ltd	(i) shale	74.8	9.0	0.56
	(ii) peelings	12.4	5.3	1.25
Fenmarc Produce Ltd	(i) shale	75.6	6.8	0.40
	(ii) tops + shale	80.0	12.6	1.03
G's Marketing Ltd	(i) shale	68.5	14.5	0.50
	(ii) whole onions	10.4	8.0	1.44
Bedfordshire Growers Ltd	(i) shale	72.5	14.9	0.44
	(ii) whole onions	10.7	5.7	1.63

The analysis of the *Brassica* and carrot waste produced by the industrial partners is shown in Table 2. In general, these wastes had a similar ash content to the wet onion waste but a lower dry matter content. In addition, the total nitrogen content of the *Brassica* waste was higher than that of the onion waste.

Table 2
Dry matter (DM), ash and total nitrogen (N) (%) content of *Brassica* and carrot waste. Each value is the mean of two replicates.

Company	Waste	DM (%)	Ash (% of DM)	Total N (% of DM)
Elgro Ltd	Broccoli stalks	8.1	6.7	1.18
	White cabbage	7.6	5.7	2.20
Fenmarc	Broccoli + cauliflower	10.8	5.0	1.99
	Wet carrot waste	8.6	4.1	1.20
G's Marketing Ltd	Whole florets of broccoli	8.9	8.1	4.75
	Whole carrots	10.9	3.4	0.92

Composting of Vegetable Waste

Composting wet bulb onion waste alone (13% dry matter) was found to be unsuitable in terms of the volume of run-off and odour produced (Table 3). A bulb onion waste mixture with a dry matter content of 20% (10:1 wet: dry waste w/w) was found to be the optimum in terms of minimising run-off. This mixture reflected the quantities of wastes produced by the industrial partners. Under these conditions the waste was found to degrade well, softening and darkening. Waste compositions drier than 20% were considered impractical in terms of the bulk of the material involved.

Table 3
Effect of bulb onion waste composition on run-off and odour produced during composting at 50 ºC for 7 days

Dry Matter Content (%)	Ratio of Wet: Dry Waste	Comments
13	1:0	Odour very strong especially in the first few days Considerable run-off (50-100 ml)
16	16:1	No unpleasant odours 1-20 ml run-off
20	10:1	No unpleasant odours Very little run-off (*c.* 1 ml)

Similar to the bulb onion waste, run-off produced by the salad onion waste varied with the moisture content of the waste mixture. The 80% moisture content mixture produced no run-off although the end product was very dry and straw-like; the 85% moisture content mixture produced some run-off but the mixture was more onion based in appearance; and the 90% moisture content mixture produced considerable run-off (*c*. 260 ml per 750 g waste). None of the mixtures produced unpleasant odours.

Similar to the onion waste, the *Brassica*- and carrot-onion shale mixtures prepared to an 80% moisture content produced little run-off (Table 4) or unpleasant odours when composted. Weight loss from the vegetable waste during composting ranged from 5.8-12.9%. Typical values for dry matter and ash content of the vegetable wastes before and after composting are detailed in Table 4. Dry weight of the onion, carrot and broccoli floret waste mixtures was lower after composting as water produced from respiration exceeded moisture losses in composting. Due to loss of carbon, ash content was higher after composting than before.

Table 4

Dry weight (%) and ash content (%) (before and after composting), weight loss (%) and run-off (ml) from vegetable wastes mixed with onion shale composted for 7 days at 50 ºC.

Waste + Onion Shale	Dry Weight of Waste Mixture (%)		Ash Content (%)		Weight Loss (%)	Run-off (ml)
	Before	After	Before	After		
Onion peelings	22.1	19.3	7.2	13.9	10.0	0
Broccoli stalks	12.6	12.5	6.1	6.3	12.9	9
White cabbage	11.9	12.3	7.3	8.5	8.3	11
Broccoli + cauliflower waste	13.7	14.9	5.6	5.7	7.0	7
Wet carrot waste	22.5	20.7	5.0	5.3	5.8	1
Whole florets of broccoli	17.2	15.5	5.2	7.9	6.4	1
Whole carrots (chopped)	23.3	18.7	4.8	7.4	8.4	0

Typical CO_2 and O_2 levels measured in the flasks during composting of the waste are detailed in Table 5. Carbon dioxide levels were higher in the composting *Brassica* wastes than in the composting onion or carrot wastes. Oxygen concentration was lowest in the composting broccoli + cauliflower waste. No ammonia was detected. This was presumably due to the acidic nature of the waste mixtures, see below, preventing hydrolysis of ammonium ions with subsequent loss of ammonia.

Table 5

CO_2 and O_2 (%) levels detected in flasks of vegetable waste mixed with onion shale after 2 days composting at 50 ºC

Waste + Onion Shale	CO_2	O_2
Onion peelings	1.5	19.5
Broccoli stalks	5.5	19.0
White cabbage	5.0	16.2
Broccoli + cauliflower	8.5	13.0
Wet carrot waste	2.5	20.1
Whole florets of broccoli	5.0	18.0
Whole carrots (chopped)	4.0	17.1

All the composted wastes sampled were found to be acidic, with mixtures containing broccoli waste being least acidic (Table 6). Conductivities ranged from 0.68-1.88 mS (Table 6).

Table 6

pH and conductivity (mS) of vegetable waste + onion shale composted for 7 days at 50 ºC. Values are the mean of two measurements.

Waste + Onion Shale	PH	Conductivity
Onion peelings	3.82	0.68
Broccoli stalks	4.75	1.04
White cabbage	4.67	0.98
Broccoli + cauliflower waste	5.97	1.13
Wet carrot waste	3.65	1.10
Whole florets of broccoli	6.62	1.88
Whole carrots (chopped)	4.14	0.99

Nitrogen, phosphorus and potassium were present in the three categories of waste, onion, *Brassica* and carrot, although their quantities varied (Table 7). The onion waste was found to have the lowest amounts of phosphorus and potassium with the *Brassica* waste having the highest nitrogen and potassium content, and the carrot waste the lowest nitrogen and highest phosphorus.

Table 7
Analysis of vegetable waste (no urea added) composted with onion shale for 7 days at 50 ºC. All values are based on percentage fresh weight.

Waste + Onion Shale	Total Nitrogen	Ammonia Nitrogen	Phosphorus	Potassium
Onion peelings	0.57	0.01	0.08	0.65
Broccoli + cauliflower waste	0.79	0.02	0.09	1.40
Whole carrots	0.46	<0.01	0.10	1.05

Elimination of Pathogens from Infested Vegetable Waste (Milestone 2.1)

Effect of Temperature and Aeration on the Survival of Pathogens

S. cepivorum

The results of preliminary experiments are detailed in Table 8. In most experiments a temperature of 40 ºC and above was found to destroy all sclerotia incubated in the onion waste in the flasks. In contrast, the viability of the sclerotia held in the nozzles in the lids of the multiadapter flasks was not as greatly affected. Indeed, the sclerotia in the nozzles of the flasks held at 40 ºC and 55 ºC showed no reduction in viability compared with the controls. Interestingly, the sclerotia in the flask nozzles tended to be colonised by a large number of contaminants.

Table 8
Germination (%) of sclerotia held in onion waste in flasks and in the flask nozzles incubated for up to 7 days at a variety of temperatures. Values are the mean of 3 replicates ± 1 SE. Germination of control sclerotia = 96% to 100%.

Temperature	Incubation (Days)					
	3		5		7	
	Flask	Nozzle	Flask	Nozzle	Flask	Nozzle
40 ºC	0	98.7 ± 1.33	0	98.0 ± 1.15	0	98.0 ± 0
50 ºC	0	96.3 ± 0.33	2.0 ± 1.53	88.0 ± 6.66	1.0 ± 1.00	61.7 ± 11.21
55 ºC	0	92.0 ± 4.62	0	95.3 ± 2.40	0	92.7 ± 4.67
60 ºC	0	84.0 ± 6.93	0	76.7 ± 5.21	0	48.7 ± 12.35

The effect of increasing temperature on germination of *S. cepivorum* is shown in Figure 1. As incubation temperature was increased percentage germination decreased with no germination after 3 and 7 days incubation at temperatures of 48 ºC and above. Incubation of sclerotia in each of the *Brassica* and carrot wastes with onion shale at 50 ºC for 7 days was also found to decrease percentage germination to zero.

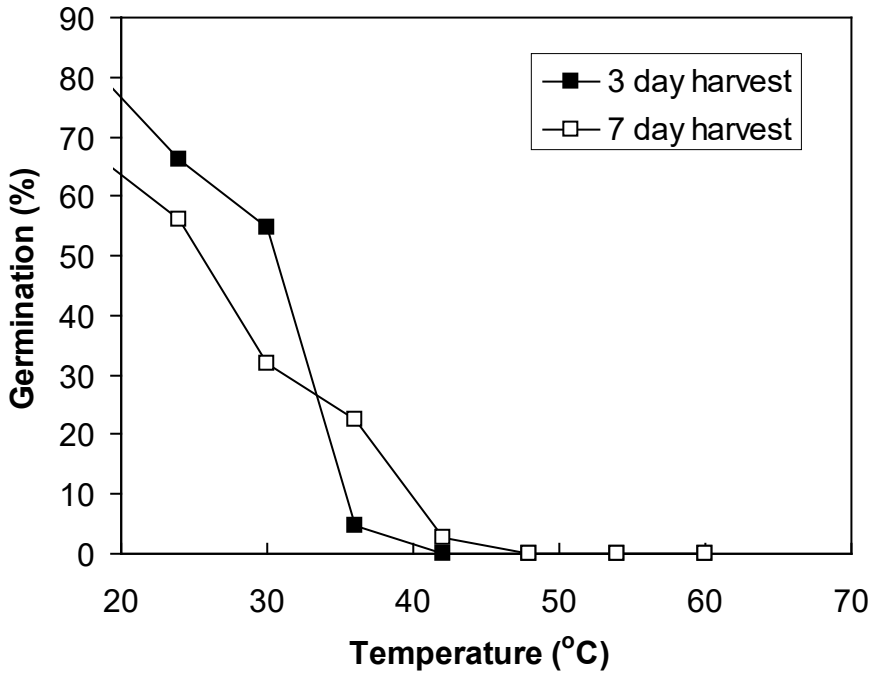

Figure 1
Effect of temperature and incubation period (days) on germination (%) of sclerotia held in onion waste. Values are the mean of 3 replicates.

O. brassicae

Symptoms of the virus transmitted by *O. brassicae*, Lettuce Big Vein Virus (LBVV), were apparent on control plants inoculated with the pathogen and spores of the fungus were visible in the plant roots. However, no symptoms of LBVV were present in the plants grown in sand inoculated with *O. brassicae* spores which had been incubated in onion waste at 50 ºC for 7 days.

F. oxysporum

The results of a preliminary experiment involving *F. oxysporum* are detailed in Table 9. Temperatures of 40 ºC and 50 ºC were not sufficient to destroy all propagules although viability compared with the control was greatly reduced.

Table 9

Propagules of *F. oxysporum* recovered after 7 days incubation at 40 ºC and 50 ºC in flasks of onion waste (2 flasks at each temperature). Each value is the mean of two replicates.

Treatment	Cfu/g soil
Control	9.6×10^3
40 ºC	6.0×10^2
40 ºC	7.7×10^3
50 ºC	5.0×10^1
50 ºC	<100

Elimination of Pests from Infested Vegetable Waste (Milestone 2.1)

Both the onion fly larvae (*Delia antiqua*) and the nematode, *Steinernema feltiae* were sensitive to the composting conditions (50 ºC for 7 days) and were destroyed during the incubation period.

Sclerotia Stimulant Activity of Composted Vegetable Waste (Milestones 3.1, 3.2)

The GC-MS analysis of the onion waste composted at 42 ºC and 54 ºC over 3 and 7 days is detailed in Table 10. The fresh onion waste was found to contain more di-n-propyl disulphide (dpds) than the composted wastes. In general, however, there was no difference in dpds content between the waste composted at 42 ºC and 54 ºC for 3 and 7 days. No diallyl disulphide (DADS) was detected in the fresh or composted waste.

Table 10: GC-MS analysis of composted onion waste

Compound (mg/kg onion waste)	**3 days at 42 ºC**			**7 days at 42 ºC**			**Fresh Onion Shale**
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
di-n-propyl disulphide	0.02	0.01	0.01	0.01	0.01	0.01	0.05
Methyl mercaptan	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
n-propyl mercaptan	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Dimethyl disulphide	<0.10	<0.10	<0.10	0.02	<0.10	<0.10	<0.10
di-n-propyl sulphide	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10

Compound (mg/kg onion waste)	**3 days at 54 ºC**			**7 days at 54 ºC**			**Fresh Peelings**
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
di-n-propyl disulphide	<0.01	0.01	0.01	<0.01	0.02	0.01	0.05
Methyl mercaptan	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
n-propyl mercaptan	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Dimethyl disulphide	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
di-n-propyl sulphide	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10

Onion Waste Pot Bioassay in Sandy Loam

Sclerotia were retrieved after **1, 2, 3 and 6 months** exposure to various rates of raw onion waste and onion waste composted for 3 or 7 days at 42 ºC or 54 ºC in **sandy loam** soil. The results of the pot bioassay are presented in Figures 2, 3 and 4. The full data set of the pot bioassay can be found in Appendix II. The viability of sclerotia in the soil, in terms of percentage soft sclerotia, was influenced by the presence and condition of the waste. Incorporation of raw waste, or of waste incubated at 42 ºC, had no effect on the percentage of soft sclerotia retrieved relative to the control (Figure 2). The percentage of soft sclerotia was however increased in the presence of waste incubated at 54 ºC ($P<0.001$) (means of all exposure times) with the waste incubated for 7 days slightly more effective than that incubated for 3 days (Figure 2).

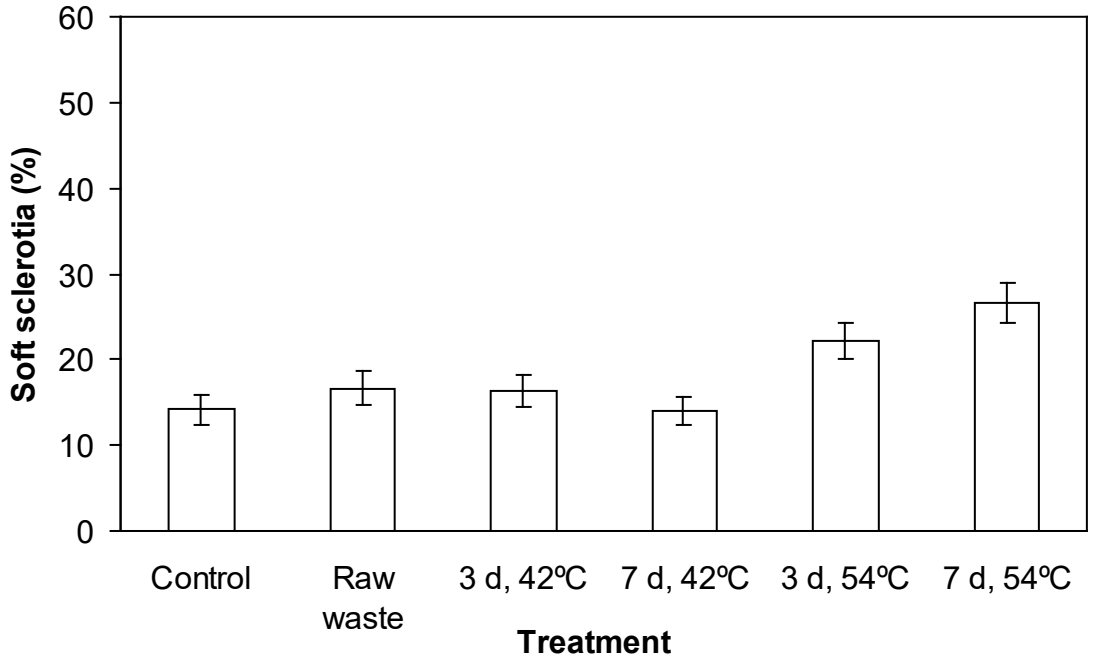

Figure 2
Effect of incubation period (d) and temperature (ºC) of onion waste on the percentage of soft sclerotia retrieved from the **sandy loam** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions, averaged across incorporation rate, exposure time and replicate for the waste treatments, and across exposure time and replicate for the untreated control. There were no soft sclerotia in the initial stock of conditioned sclerotia.

In addition to the effect of incubation temperature, the rate of waste incorporation ($P<0.001$) and the duration of exposure of the sclerotia to the waste ($P<0.001$) both had effects on the percentage soft sclerotia retrieved (Figure 3). As only the high incubation temperature had a significant effect on the percentage of soft sclerotia retrieved (Figure 2), the effects of incorporation rate and exposure duration are only shown for waste incubated at 54 ºC (Figure 3). Relative to the control, the 1% rate of the waste incubated at 54 ºC only increased the percentage of soft sclerotia retrieved after 6 months exposure, whilst the 10% rate increased this percentage after both 3 and 6 months exposure (Figure 3). The 50% rate was the most effective in terms of the speed of effect, with an increase in the percentage of soft sclerotia retrieved recorded at all sample dates (Figure 3). The 10% and 50% rates showed the largest increase in percentage soft sclerotia after 6 months exposure.

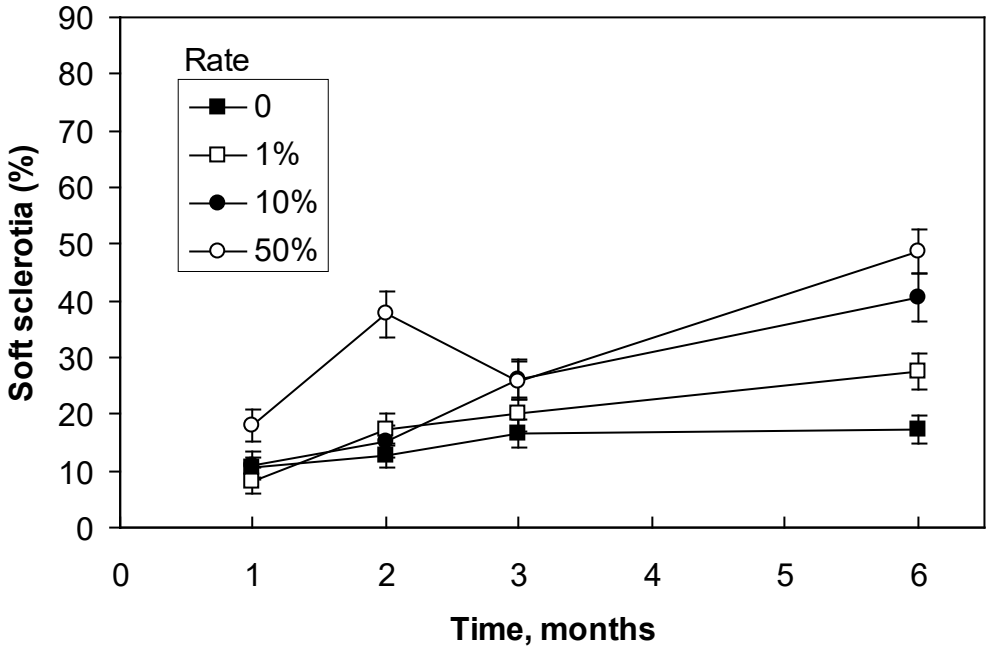

Figure 3
Effect of rate of incorporation of onion waste and duration of exposure on the percentage of soft sclerotia retrieved from the pot bioassay with **sandy loam** soil mixed with onion waste incubated at 54 ºC. Values shown (mean ± SE) were obtained from predicted mean proportions for the 54 ºC incubation temperature treatment, averaged across incubation period and replicate, and for the untreated control, averaged across replicate only. There were no soft sclerotia in the initial stock of conditioned sclerotia.

In addition to affecting the percentage of soft sclerotia, the rate of incorporation of the waste had an effect on the germination of hard sclerotia retrieved. The 50% rate of the raw and composted wastes reduced germination ($P<0.001$) relative to the control, with the composted waste considerably more effective than the raw waste (Figure 4). In contrast, the 1% and 10% rates of the raw and composted wastes had no effect on the germination of retrieved sclerotia (Figure 4). Unlike the percentage of soft sclerotia, there was no significant effect of duration of exposure to waste on the germination of hard sclerotia retrieved.

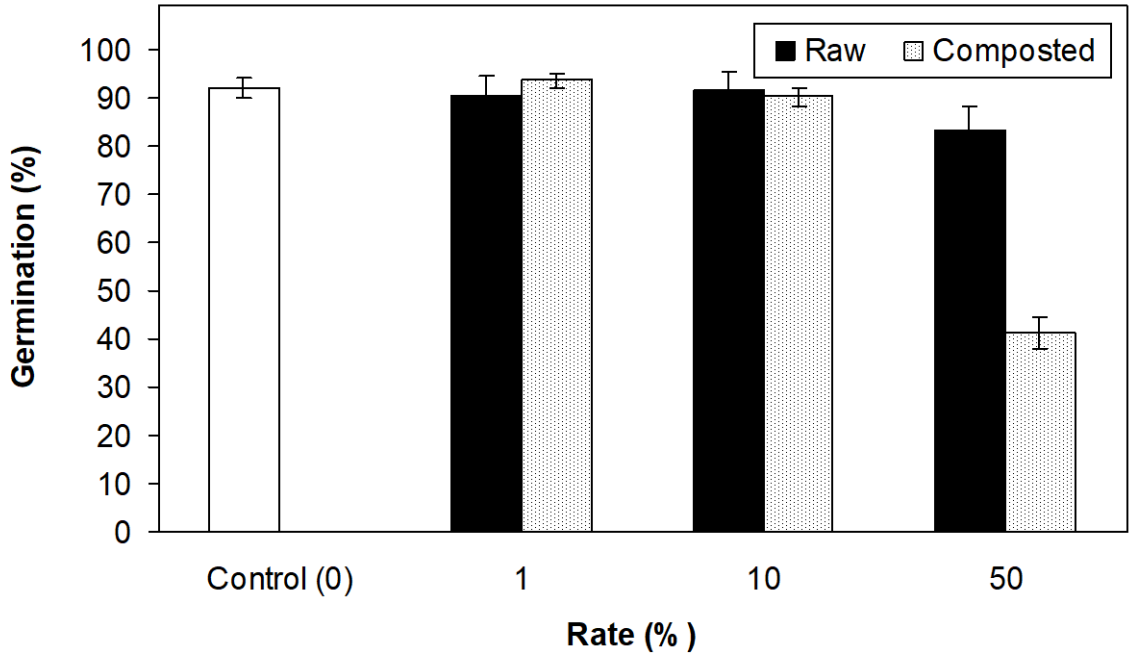

Figure 4
Effect of rate of incorporation and condition of onion waste on percentage germination of sclerotia retrieved from the **sandy loam** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from the predicted mean proportions averaged across exposure time and replicate for all treatments, and across incubation period and temperature for the composted waste treatments.

Brassica Waste, Carrot Waste + Onion Shale Pot Bioassay in Sandy Loam

Sclerotia were retrieved after **1, 2, 3 and 6 months** exposure to various rates of raw and composted vegetable waste (white cabbage, broccoli florets, whole carrots, wet carrot waste, broccoli stalks and broccoli & cauliflower waste) mixed with onion shale in **sandy loam** soil. The results of the pot bioassay are presented in Figures 5, 6, 7 and 8. The full data set of the pot bioassay can be found in Appendix II. The viability of sclerotia in the soil, in terms of soft sclerotia, was influenced by the presence of the waste. All vegetable waste types increased percentage soft sclerotia relative to the control (P=0.008) (Figure 5) with the composted waste slightly more effective than the raw waste (P<0.001).

The rate of incorporation (P<0.001) and duration of exposure (P=0.022) of the sclerotia to the waste also had an effect on soft sclerotia retrieved. All three rates of all waste types increased the percentage of soft sclerotia retrieved relative to the control (Figure 5). The percentage soft sclerotia retrieved from the soil-vegetable waste mixtures increased over time, with the 50% rate showing the largest increase after 6 months exposure (Figure 6). The 50% rate of the wet carrot waste was the most effective treatment (Figure 5).

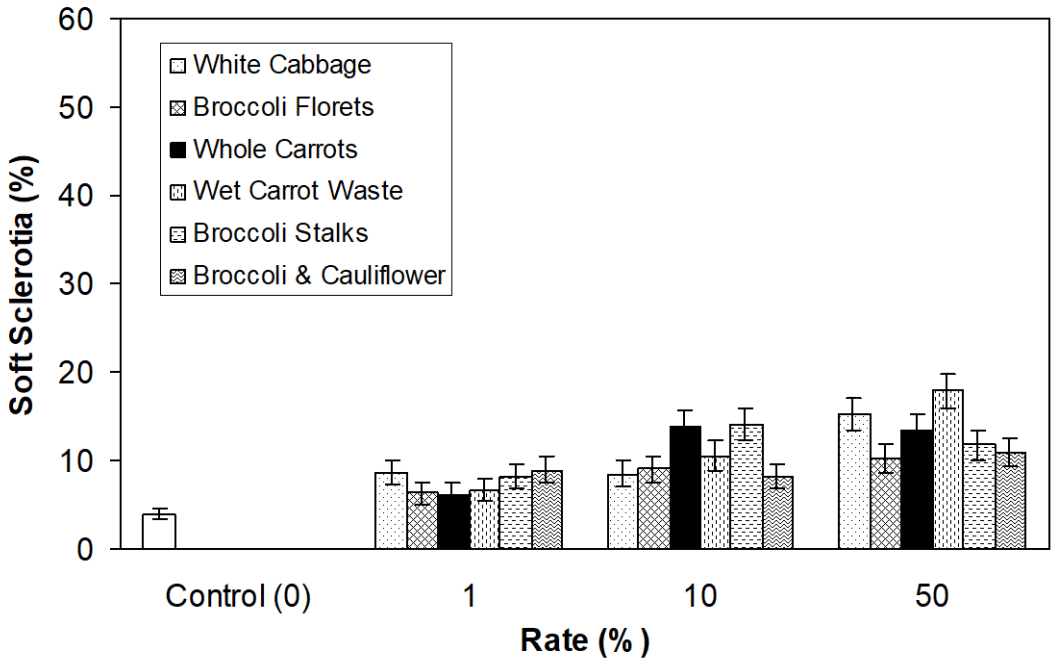

Figure 5
Effect of waste type and rate of incorporation on the percentage of soft sclerotia retrieved from the **sandy loam** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions, averaged across condition of the waste, exposure time and replicate for the waste treatments, and across exposure time and replicate for the untreated control. There were no soft sclerotia in the initial stock of conditioned sclerotia.

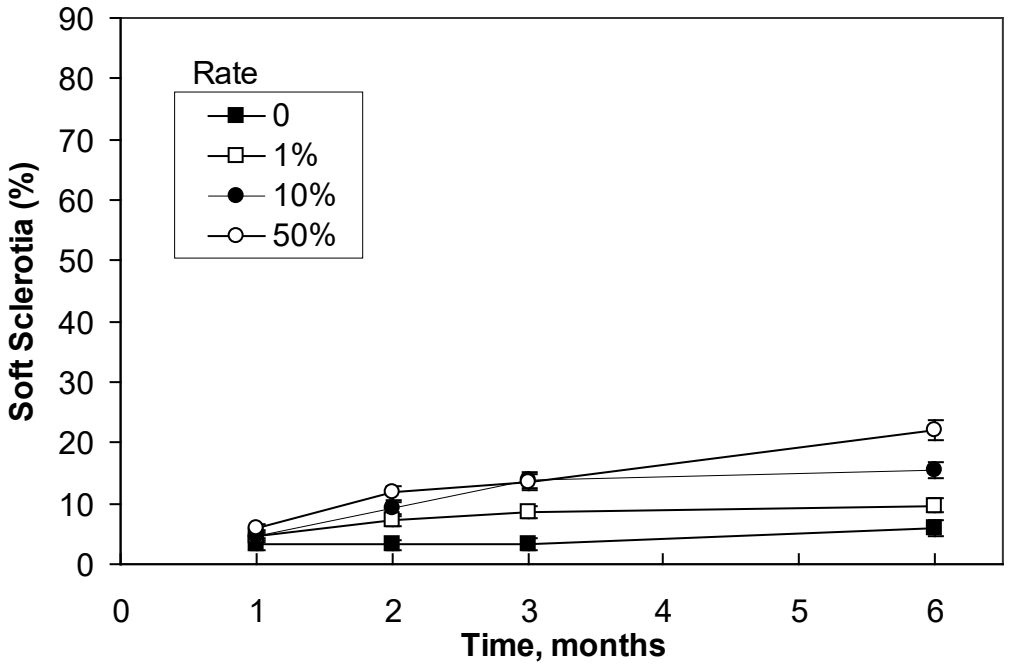

Figure 6
Effect of rate of incorporation and duration of exposure on the percentage of soft sclerotia retrieved from the **sandy loam** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions, averaged across waste type, condition and replicate, and for the untreated control, averaged across replicate only. There were no soft sclerotia in the initial stock of conditioned sclerotia

The presence of the waste also reduced percentage germination of hard sclerotia retrieved. Figure 7 shows the effect of the 50% incorporation rate of the different waste types on germination of retrieved sclerotia. The presence of each of the waste types reduced germination relative to the control (Figure 7). The composted waste was more effective than the raw waste ($P<0.001$). The effect of the vegetable wastes on germination increased over time, with the largest reduction in germination recorded after 6 months exposure to the 50% rate (Figure 8). Similar to the results for soft sclerotia, the 50% rate of the wet carrot waste was the most effective treatment (Figure 7).

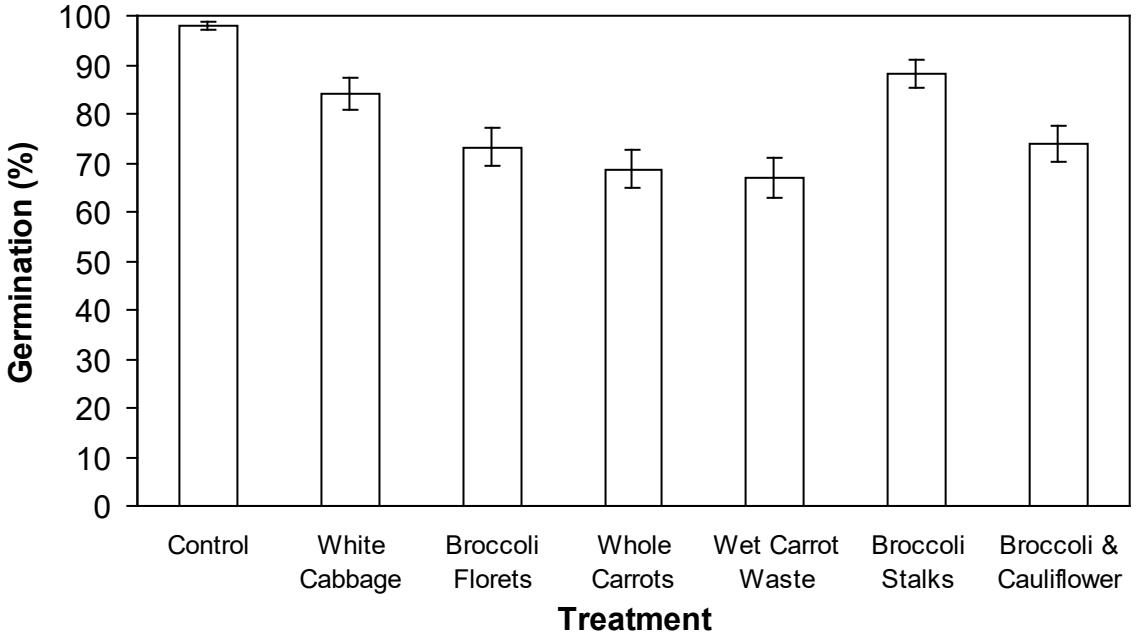

Figure 7
Effect of waste type on percentage germination of sclerotia retrieved from the **50% rate** of the **sandy loam** pot bioassay soil-waste mixtures (1-6 months burial). Values shown (mean ± SE) were obtained from predicted mean proportions averaged across condition of the waste, exposure time and replicate for all treatments, and across exposure time and replicate for the untreated control.

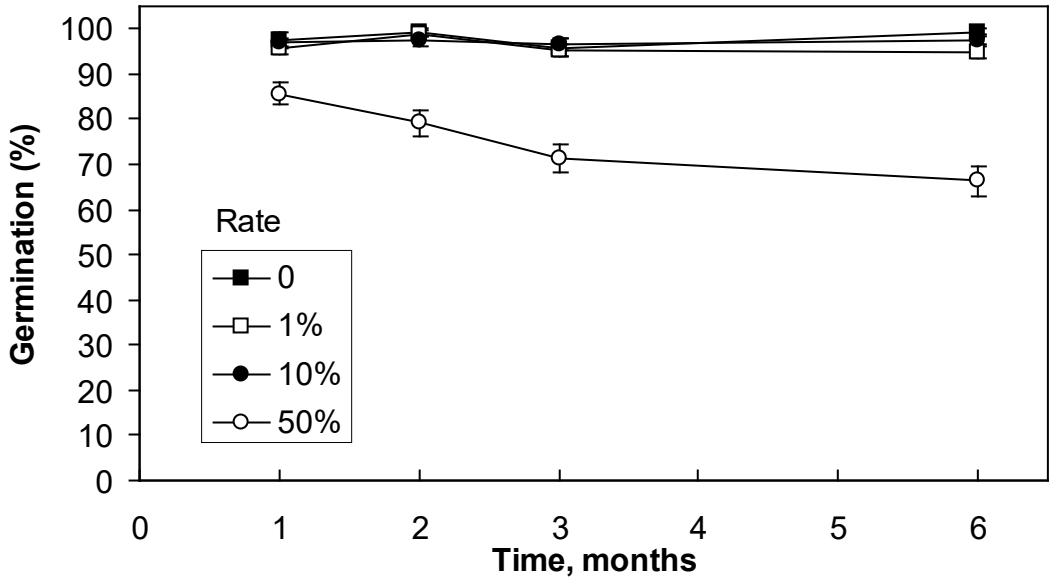

Figure 8
Effect of rate of incorporation and duration of exposure on percentage germination of sclerotia retrieved from the **sandy loam** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions, averaged across waste type, condition and replicate, and for the untreated control, averaged across replicate only.

Onion and Other Vegetable Waste Pot Bioassay in Sandy Loam

Sclerotia were retrieved after **9 and 12 months** exposure to various rates of raw and composted vegetable waste (white cabbage, broccoli florets, whole carrots and onion peelings) mixed with onion shale in **sandy loam** soil. The full data set of the pot bioassay can be found in Appendix II. Similar to the two previous bioassays in sandy loam soil, the viability of sclerotia, in terms of soft sclerotia retrieved, was influenced by the presence of the waste ($P<0.001$). Incorporation of all waste types increased the percentage of soft sclerotia retrieved relative to the control ($P<0.001$) (Figure 9). In addition, the rate of incorporation of the waste had an effect on viability ($P<0.001$). The percentage of soft sclerotia increased with incorporation rate with the largest increase with the 50% rate of the onion peelings (Figure 9). The raw waste was slightly more effective than the composted waste at the 50% rate ($P=0.034$).

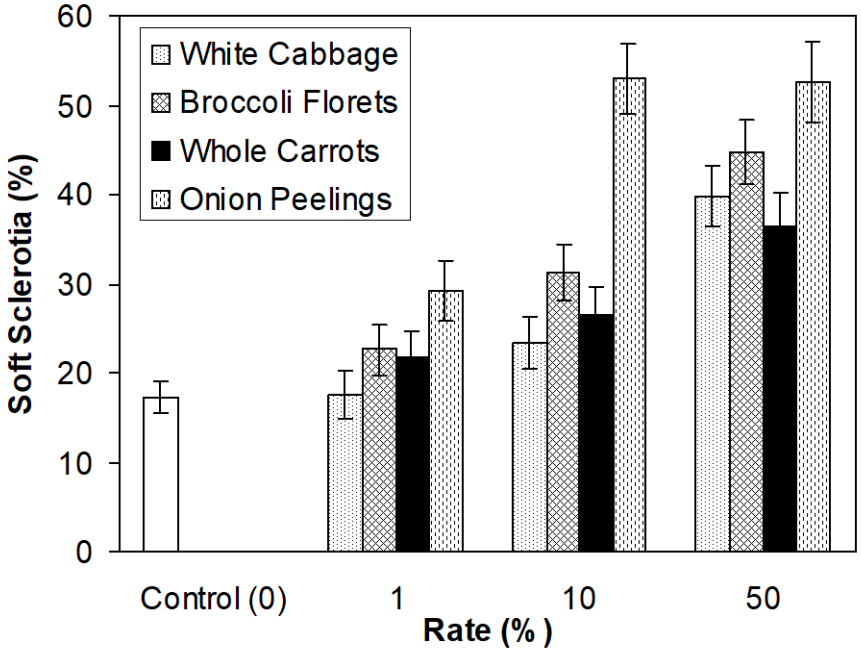

Figure 9
Effect of waste type and rate of incorporation on the percentage of soft sclerotia retrieved from the **sandy loam** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions, averaged across condition of the waste, exposure time and replicate for the waste treatments, and across exposure time and replicate for the untreated control. There were no soft sclerotia in the initial stock of conditioned sclerotia.

The presence of the waste also reduced percentage germination of hard sclerotia retrieved. Figure 10 shows the effect of the 50% incorporation rate of the different waste types on germination of retrieved sclerotia. The presence of each of the waste types reduced germination relative to the control ($P<0.001$) (Figure 10). The 50% rate of the broccoli florets was the most effective treatment (Figure 10). In contrast to the results for soft sclerotia, the composted waste was slightly more effective than the raw waste ($P=0.003$).

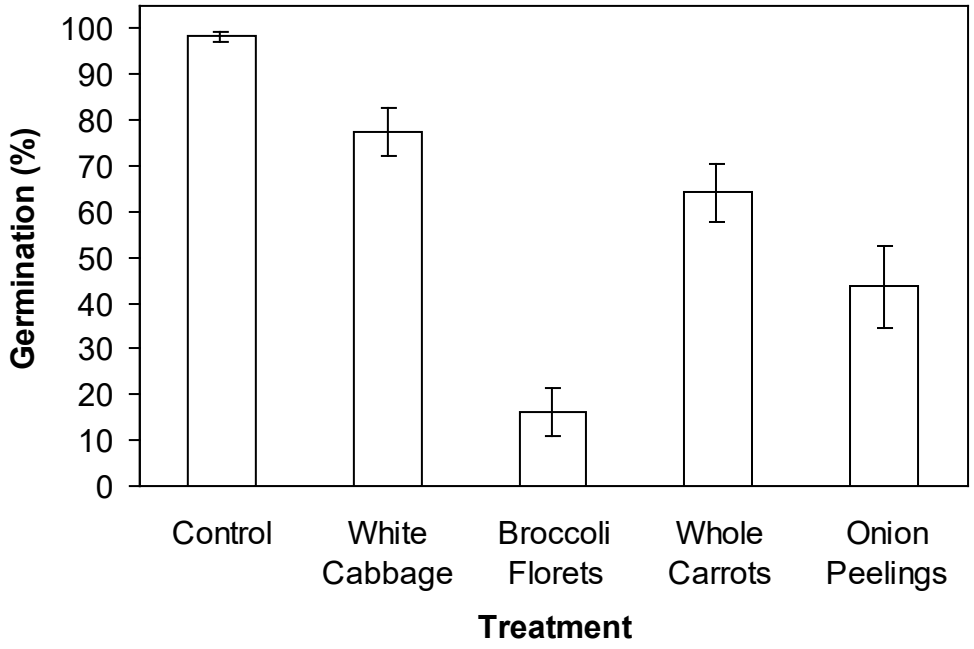

Figure 10
Effect of waste type on percentage germination of sclerotia retrieved from the **50% rate** of the **sandy loam** pot bioassay soil-waste mixtures (9-12 months burial). Values shown (mean ± SE) were obtained from predicted mean proportions averaged across condition of the waste, exposure time and replicate for all treatments, and across exposure time and replicate for the untreated control.

Onion and Other Vegetable Waste Pot Bioassay in Silt

Sclerotia were retrieved after **1, 2, 3, 6, 9 and 12 months** exposure to various rates of raw and composted vegetable waste (white cabbage, broccoli florets, whole carrots and onion peelings) mixed with onion shale in **silt** soil. The results of the pot bioassay are presented in Figures 11, 12, 13 and 14. The full data set of the pot bioassay can be found in Appendix II. The viability of sclerotia in the soil, in terms of soft sclerotia retrieved, was influenced by the presence of the waste ($P<0.001$). All vegetable waste types increased percentage soft sclerotia retrieved relative to the control ($P<0.001$) (Figure 11), with the raw waste more effective than the composted waste ($P<0.001$).

The rate of incorporation ($P<0.001$) and duration of exposure ($P<0.001$) of the sclerotia to the waste also had an effect on viability. The 10% and 50% rates of all waste types increased the percentage of soft sclerotia retrieved relative to the control, with the onion peelings being the most effective (Figure 11). The percentage soft sclerotia retrieved from the soil-vegetable waste mixtures increased over time, with the 50% rate showing the largest increase relative to the control after 12 months exposure (Figure 12).

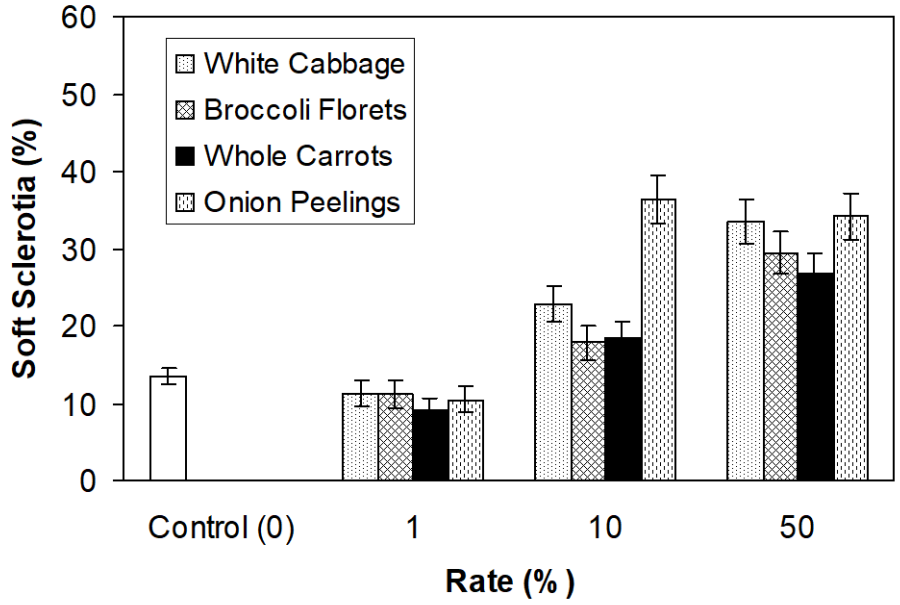

Figure 11
Effect of waste type and rate of incorporation on the percentage of soft sclerotia retrieved from the **silt** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions, averaged across condition of the waste, exposure time and replicate for the waste treatments, and across exposure time and replicate for the untreated control. There were no soft sclerotia in the initial stock of conditioned sclerotia.

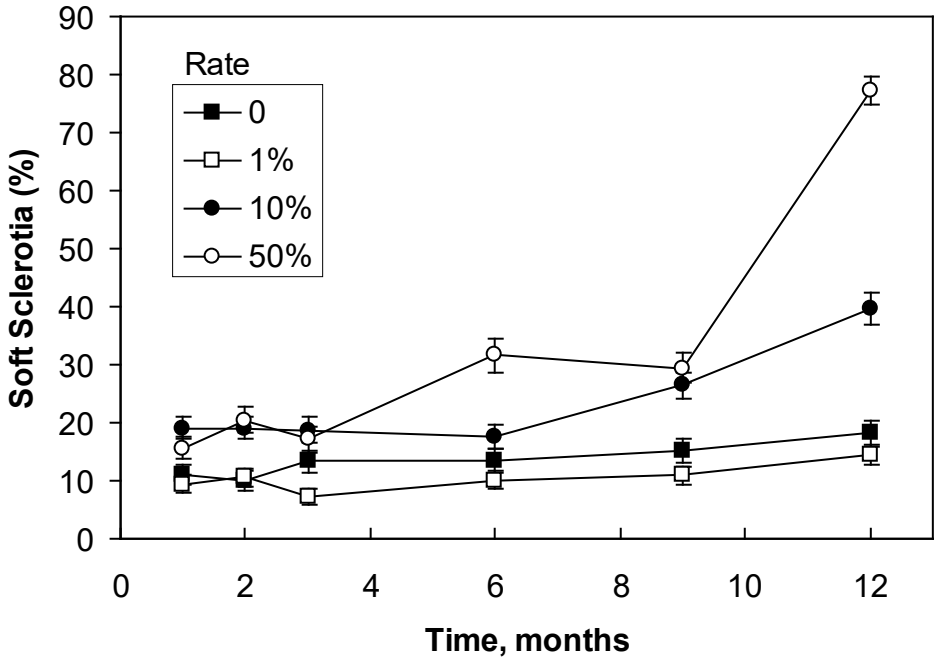

Figure 12
Effect of rate of incorporation and duration of exposure on the percentage of soft sclerotia retrieved from the **silt** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions, averaged across waste type, condition and replicate, and for the untreated control, averaged across replicate only. There were no soft sclerotia in the initial stock of conditioned sclerotia.

The presence of the waste also reduced percentage germination of hard sclerotia retrieved. Figure 13 shows the effect of the 50% incorporation rate of the different waste types on germination of retrieved sclerotia. The presence of each of the waste types reduced germination relative to the control, with the 50% rate of the broccoli florets being the most effective treatment (Figure 13). Similar to the results for soft sclerotia, the raw waste was slightly more effective than the composted waste ($P<0.001$). The 50% rate of the wastes reduced germination of retrieved sclerotia relative to the control at every sample date (Figure 14).

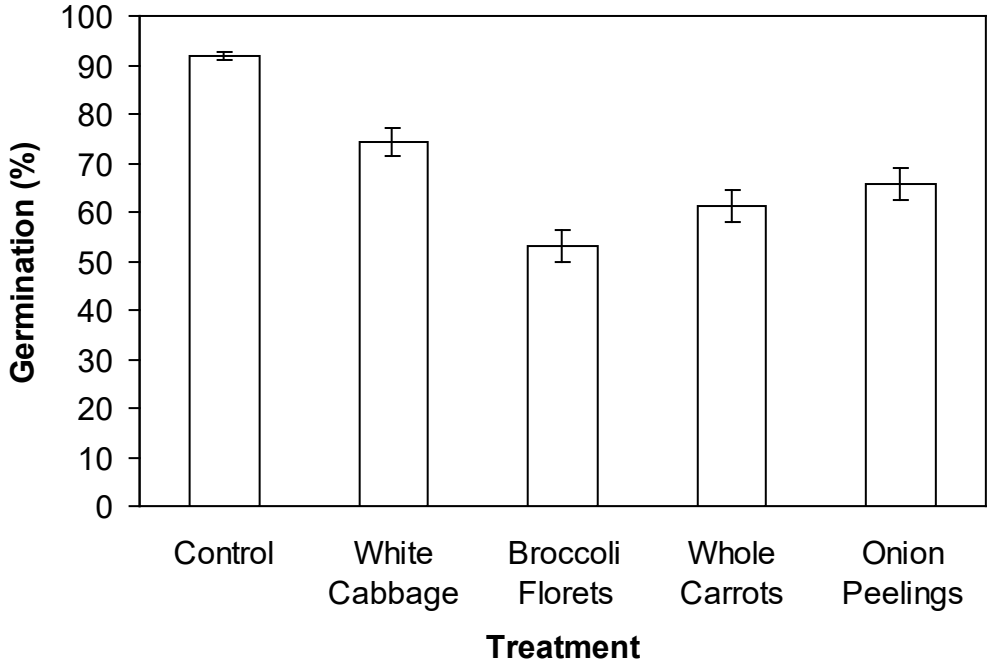

Figure 13
Effect of waste type on percentage germination of sclerotia retrieved from the **50% rate** of the **silt** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions averaged across condition of the waste, exposure time and replicate for all treatments, and across exposure time and replicate for the untreated control.

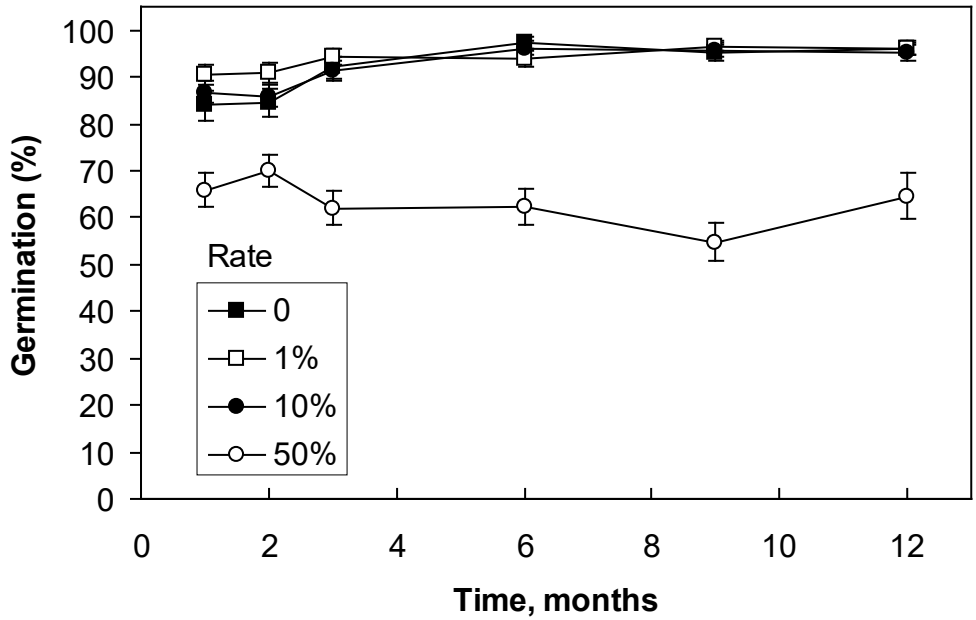

Figure 14
Effect of rate of incorporation and duration of exposure on percentage germination of sclerotia retrieved from the **silt** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions, averaged across waste type, condition and replicate, and for the untreated control, averaged across replicate only.

Onion and Other Vegetable Waste Pot Bioassay in Peat

Sclerotia were retrieved after **1, 2, 3, 6, 9 and 12 months** exposure to various rates of raw and composted vegetable waste (white cabbage, broccoli florets, whole carrots and onion peelings) mixed with onion shale in **peat** soil. The results of the pot bioassay are presented in Figures 15, 16 and 17. The full data set of the pot bioassay can be found in Appendix II. The viability of sclerotia in the soil, in terms of percentage soft sclerotia, was influenced by the presence of the waste ($P<0.001$). Based on the overall analysis, all the vegetable waste types increased percentage soft sclerotia relative to the control ($P<0.001$), with the exception of the whole carrots. The rate of incorporation also had an effect on viability ($P<0.001$). All three rates of the onion peelings increased the percentage of soft sclerotia retrieved relative to the control (Figure 15). In addition, the 10% rate of the broccoli florets and the 50% rates of the white cabbage and broccoli florets increased percentage soft sclerotia (Figure 15). There was no difference in the effectiveness between the raw and composted wastes ($P=0.121$). Unlike the results of the pot bioassays in the sandy loam and silt soils, duration of exposure to the vegetable wastes had no effect on the percentage of soft sclerotia retrieved.

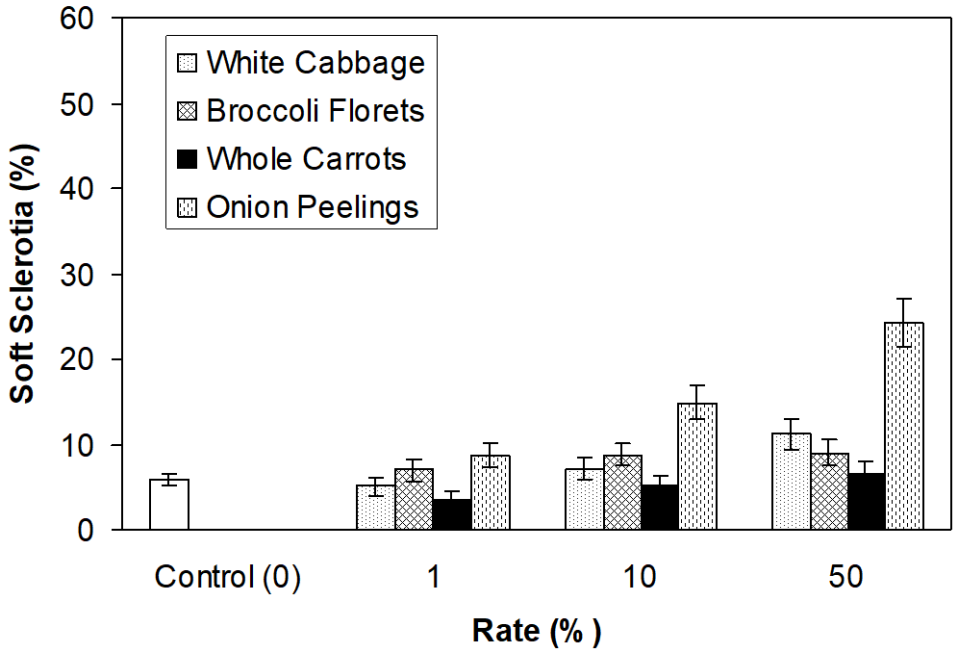

Figure 15
Effect of waste type and rate of incorporation on the percentage of soft sclerotia retrieved from the **peat** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions, averaged across condition of the waste, exposure time and replicate for the waste treatments, and across exposure time and replicate for the untreated control. There were no soft sclerotia in the initial stock of conditioned sclerotia.

The presence of the waste also reduced percentage germination of hard sclerotia retrieved. Figure 16 shows the effect of the 50% incorporation rate of the different waste types on germination of retrieved sclerotia. The presence of each of the waste types reduced germination relative to the control, with the 50% rate of the broccoli florets being the most effective treatment (Figure 16). There was no difference in the effectiveness between the raw and composted wastes (P=0.502). The 50% rate of the wastes reduced germination of retrieved sclerotia at every sample date (Figure 17).

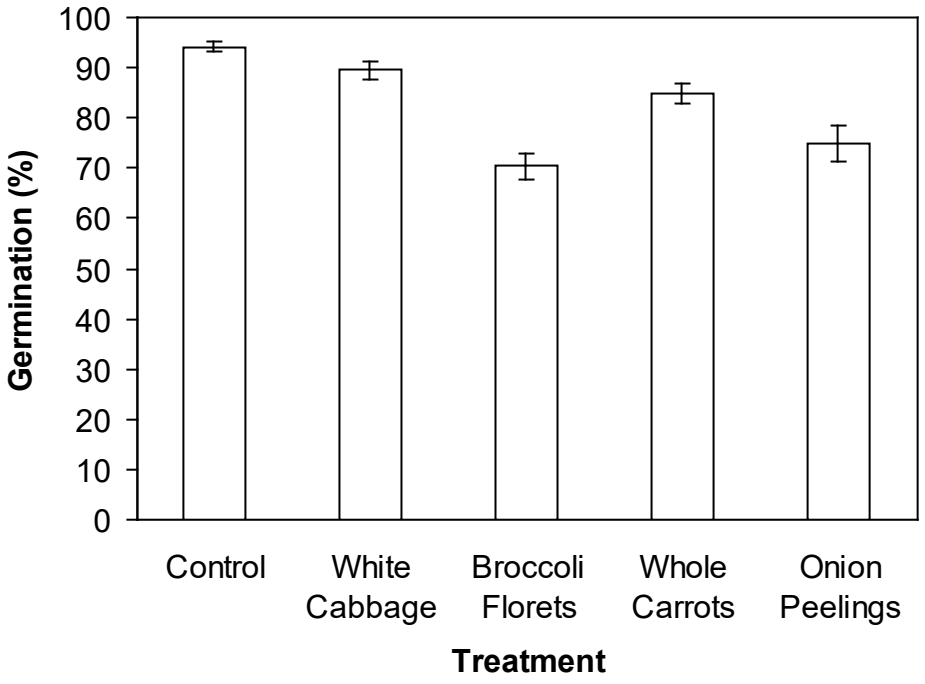

Figure 16
Effect of waste type on percentage germination of sclerotia retrieved from the **50% rate** of the **peat** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions averaged across condition of the waste, exposure time and replicate for all treatments, and across exposure time and replicate for the untreated control.

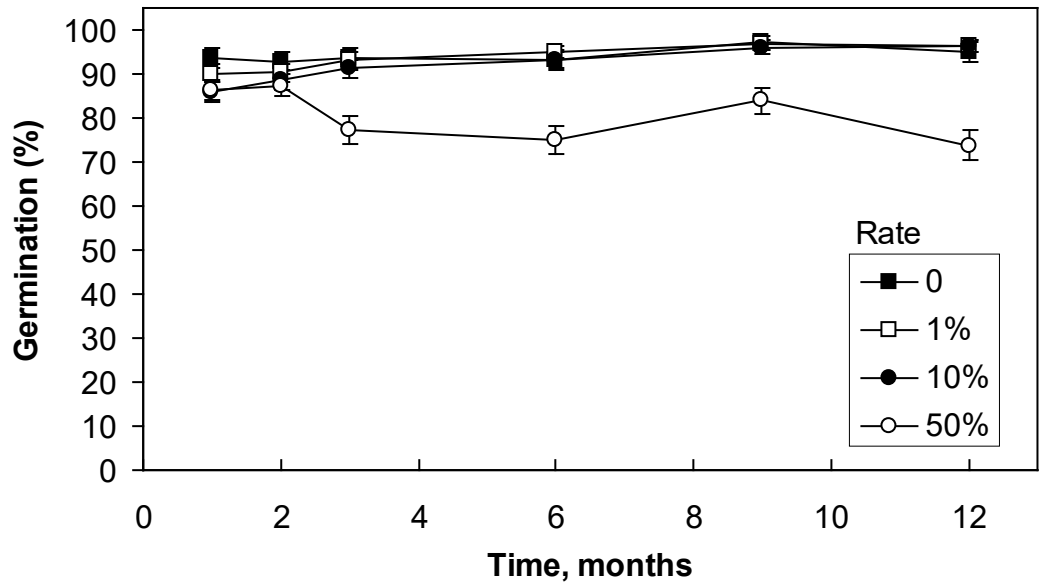

Figure 17
Effect of rate of incorporation and duration of exposure on percentage germination of sclerotia retrieved from the **peat** pot bioassay soil-waste mixtures. Values shown (mean ± SE) were obtained from predicted mean proportions, averaged across waste type, condition and replicate, and for the untreated control, averaged across replicate only.

Temperature Effects on Glasshouse Studies

The results for the percentage of soft sclerotia retrieved from the pots in the glasshouse and field after 1, 2, 3, 6 and 9 months burial are detailed in Tables 11(a) and 11(b). There were only two treatments which increased percentage soft sclerotia retrieved in the glasshouse, the 1 and 9 months burial in peat (Table 11(a)). The treatments had an effect on the soft sclerotia retrieved from the field after 6 months in the silt and peat soils (Table 11(b)). Comparison of the results in Tables 11(a) and 11(b) reveals that the percentage of soft sclerotia retrieved was generally higher from both the control and test pots in the glasshouse (Table 11(a)) than from those in the field (Table 11(b)). As expected, the air temperatures in the glasshouse and the field for months 1-3 (February, March and April) differed considerably. The mean air temperature in the glasshouse for months 1, 2 and 3 was 16 ºC, 17 ºC and 17 ºC respectively, whilst in the field the mean temperature for each of the months was 5 ºC. There was less of a difference in temperature between the two environments over the following 3 month period (May, June, July) with average temperatures of 21 ºC and 15 ºC recorded for the glasshouse and field respectively. Similarly, the average temperatures recorded in the glasshouse and field for the 3 month period August-October were 18 ºC and 15 ºC respectively.

Table 11(a)
Soft sclerotia (%) of *S. cepivorum* retrieved after 1, 2, 3, 6 and 9 months burial in sandy loam, silt and peat soil containing 50% composted onion waste in the **glasshouse**. Values are the mean of three replicate bags each containing 100 sclerotia. Unless stated otherwise, P>0.05.
SL = sandy loam soil. Waste = composted onion waste.

	1 month	**2 months**	**3 months**	**6 months**	**9 months**
Sandy loam	8.0 ± 3.79	29.0 ± 2.65	14.7 ± 2.03	41.0 ± 2.31	53.3 ± 9.21
SL + waste	8.3 ± 0.88	12.0 ± 5.00*	20.3 ± 6.23	39.3 ± 6.12	44.0 ± 5.03
		P<0.05			
Silt	8.0 ± 1.00	11.0 ± 1.15	12.3 ± 0.67	27.0 ± 6.11	29.3 ± 6.23
Silt + waste	7.7 ± 0.67	12.0 ± 7.57	16.3 ± 1.86	64.0 ± 11.01	50.7 ± 1.67
Peat	4.3 ± 0.88	14.3 ± 4.37	9.0 ± 1.53	11.3 ± 6.57	16.3 ± 4.67
Peat + waste	11.7 ± 0.88*	20.0 ± 2.65	13.3 ± 5.93	24.3 ± 4.33	39.0 ± 3.51*
	P<0.05				**P<0.05**

Table 11(b)
Soft sclerotia (%) of *S. cepivorum* retrieved after 1, 2, 3, 6 and 9 months burial in sandy loam, silt and peat soil containing 50% composted onion waste in the **field**. Values are the mean of three replicate bags each containing 100 sclerotia. Unless stated otherwise, P>0.05.
SL = sandy loam soil. Waste = composted onion waste.

	1 month	**2 months**	**3 months**	**6 months**	**9 months**
Sandy loam	2.0 ± 1.15	15.0 ± 2.52	23.7 ± 6.39	20.7 ± 4.91	23.0 ± 2.31
SL + waste	3.3 ± 0.33	5.0 ± 2.08*	9.7 ± 4.18	36.7 ± 4.67	35.0 ± 8.39
		P<0.05			
Silt	3.0 ± 0.58	2.3 ± 0.33	5.0 ± 1.00	13.0 ± 5.03	28.0 ± 5.51
Silt + waste	2.0 ± 1.00	3.7 ± 2.03	18.3 ± 3.76	44.0 ± 4.00*	47.3 ± 5.84
				P<0.05	
Peat	3.3 ± 2.03	3.3 ± 0.88	7.7 ± 3.28	9.7 ± 2.67	17.0 ± 6.51
Peat + waste	1.3 ± 0.33	3.7 ± 1.67	7.7 ± 4.63	24.0 ± 1.53*	23.0 ± 7.37
				P<0.05	

The results for the percentage germination of sclerotia retrieved from the pots in the glasshouse and field after 1, 2, 3, 6 and 9 months burial are detailed in Tables 12(a) and 12(b). No effect on germination was recorded for sclerotia retrieved from the sandy loam soil treatments in either the glasshouse or the field. The presence of the composted waste did however have an effect on the sclerotia in the silt soil in the glasshouse. Germination of retrieved sclerotia was reduced after 1, 2 and 3 months burial but there was no effect on the sclerotia retrieved after 6 and 9 months burial (Table 12(a)). In contrast, no effect was observed in this soil in the field until the 6 month sampling (Table 12(b)). The presence of the composted waste also had an effect on the sclerotia in the peat soil in both the glasshouse and field. Exposure to

the waste for 3 months or longer in the peat soil in the glasshouse reduced percentage germination of retrieved sclerotia. In contrast, only the germination of the sclerotia retrieved after 2 months burial in the peat soil in the field was reduced in the presence of the waste.

Table 12(a)

Germination (%) of sclerotia of *S. cepivorum* retrieved after 1, 2, 3, 6 and 9 months burial in sandy loam, silt and peat soil containing 50% composted onion waste in the **glasshouse**. Values are the mean of three replicate bags each containing 100 sclerotia. Unless stated otherwise, P>0.05.
SL = sandy loam soil. Waste = composted onion waste.

	1 month	**2 months**	**3 months**	**6 months**	**9 months**
Sandy loam	75.7 ± 12.86	79.0 ± 6.66	74.7 ± 2.33	72.7 ± 14.44	88.3 ± 0.33
SL + waste	45.3 ± 21.26	47.7 ± 12.45	49.3 ± 16.60	39.3 ± 8.25	37.0 ± 14.84
Silt	82.0 ± 1.00	82.0 ± 9.54	89.7 ± 3.33	99.0 ± 1.00	100.0 ± 0
Silt + waste	39.0 ± 9.54*	32.3 ± 13.86*	17.7 ± 7.42*	42.7 ± 22.76	36.3 ± 18.21
	P<0.05	**P<0.05**	**P<0.05**		
Peat	84.3 ± 7.22	90.0 ± 1.73	89.3 ± 3.48	99.0 ± 1.00	97.7 ± 2.33
Peat + waste	86.3 ± 3.33	84.0 ± 8.33	66.3 ± 4.70*	51.7 ± 4.41*	76.0 ± 2.65
			P<0.05	**P<0.05**	**P<0.05**

Table 12(b)

Germination (%) of sclerotia of *S. cepivorum* retrieved after 1, 2, 3, 6 and 9 months burial in sandy loam, silt and peat soil containing 50% composted onion waste in the **field**. Values are the mean of three replicate bags each containing 100 sclerotia. Unless stated otherwise, P>0.05.
SL = sandy loam soil. Waste = composted onion waste.

	1 month	**2 months**	**3 months**	**6 months**	**9 months**
Sandy loam	61.0 ± 11.59	57.7 ± 3.93	64.7 ± 13.00	84.3 ± 8.69	86.7 ± 8.41
SL + waste	35.7 ± 18.41	32.3 ± 16.19	57.7 ± 7.42	55.7 ± 11.57	67.0 ± 12.34
Silt	73.3 ± 6.89	86.7 ± 4.91	86.7 ± 4.91	89.0 ± 2.00	98.0 ± 1.00
Silt + waste	71.3 ± 7.22	67.7 ± 13.86	77.7 ± 7.42	51.3 ± 5.93*	59.7 ± 25.43
				P<0.05	
Peat	84.3 ± 8.09	95.7 ± 1.33	83.3 ± 5.24	93.3 ± 3.33	64.3 ± 32.23
Peat + waste	61.0 ± 9.87	72.3 ± 7.67*	90.7 ± 1.20	45.7 ± 23.78	78.0 ± 9.02
		P<0.05			

Control of *Allium* White Rot with Composted Onion Waste (Milestone 4.2)

Seed Pot Bioassay 1

The results of the first pot bioassay, using onion seeds, testing the control of *Allium* white rot with composted onion waste are presented in Figure 18. The plants were 3 weeks old before any disease was detected and no disease was detected in the plants in the silt soil until week 6. The percentage of diseased plants increased over time, most noticeably in the control treatments (soil alone) in the sandy loam and peat soils. Good disease control was achieved in the peat soil with the waste incorporation. No disease control was achieved in the sandy loam or silt soils, although the percentage infection of the test plants was low. No disease was detected in the uninoculated pots.

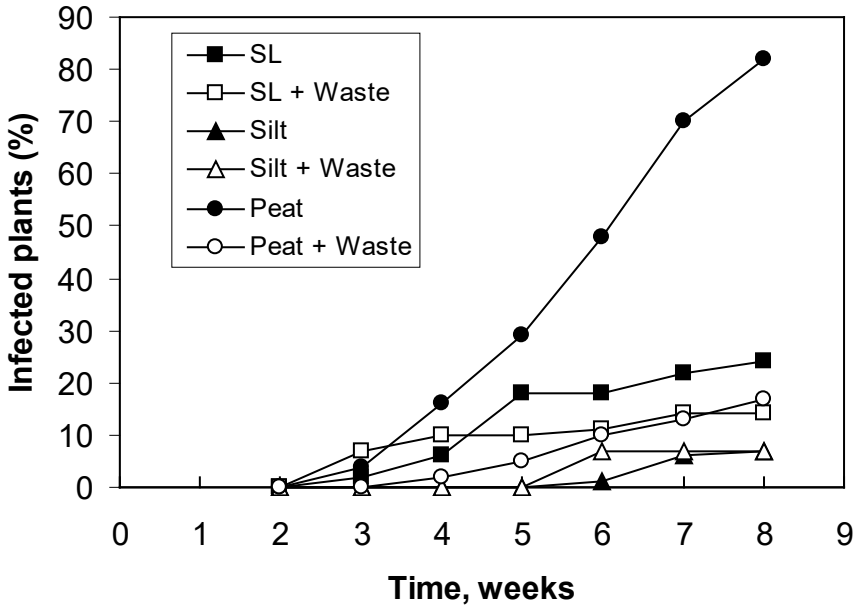

Figure 18

Onion plants (%) infected with *Allium* white rot in 3 soil types (sandy loam (SL), silt and peat) containing composted onion waste (waste) (50% incorporation rate) inoculated with 3 sclerotia/g of mixture. Values are the mean of 50 replicate pots.

Seed Pot Bioassay 2

The results of pot bioassay 2 using onion seeds are presented in Figure 19. Disease was detected in the control (soil alone) and test (soil + waste) plants in the peat and silt soils after 4 weeks, and in the control plants in the sandy loam soil after 3 weeks. The percentage of diseased plants increased over time, most noticeably in the control treatments. Similar to the first pot bioassay, good disease control was achieved in the peat soil with the percentage infection of test plants almost half that of the controls. There was no disease control in the silt soil although, similar to the first pot bioassay, percentage infection of the control plants was quite low. A high level of infection was detected in the control plants in the sandy loam soil but, unlike the results of the first pot bioassay, no disease was detected in the test plants. No disease was detected in the three soil types in the uninoculated pots.

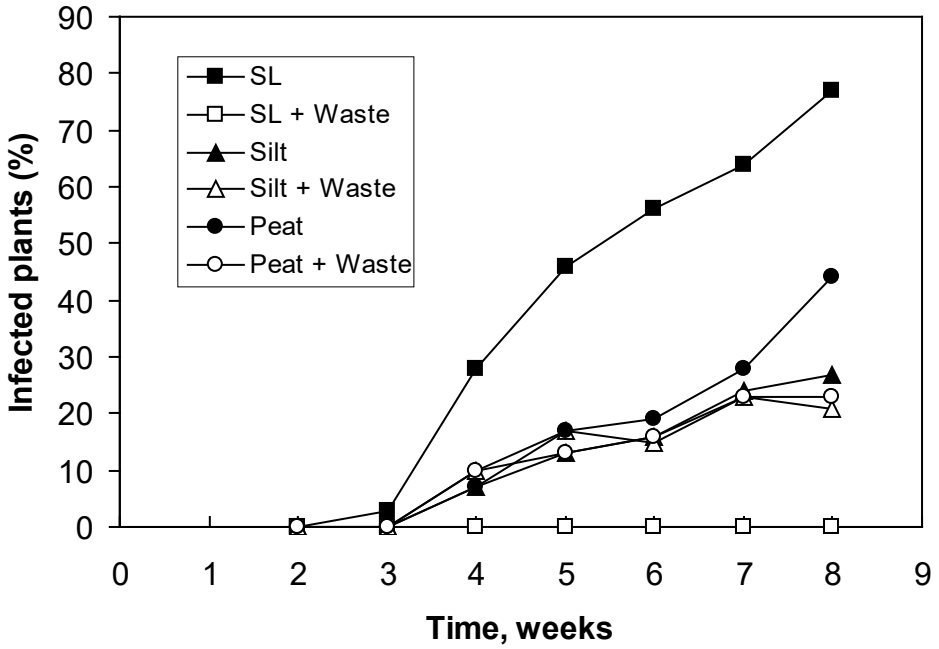

Figure 19

Onion plants (%) infected with *Allium* white rot in 3 soil types (sandy loam (SL), silt and peat) containing composted onion waste (waste) (50% incorporation rate) inoculated with 3 sclerotia/g of mixture. Values are the mean of 50 replicate pots.

Germination in Seed Pot Bioassays 1 and 2

Figures 20 and 21 show the germination of onion seeds in the different uninoculated treatments in pot bioassays 1 and 2. In both pot bioassays, seed germination was higher in each of the soil types compared with that in the soils + waste treatments. Germination in the silt + waste treatment in pot bioassay 1 (Figure 20) and in the sandy loam + waste treatment in pot bioassay 2 (Figure 21) was particularly low.

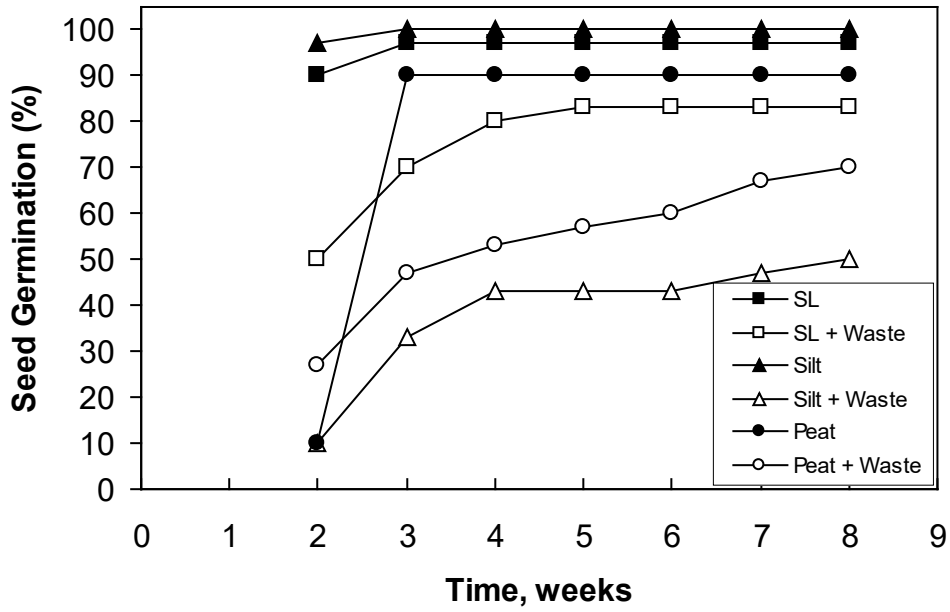

Figure 20
Germination of onion seed (Pot Bioassay 1) in 3 soil types (sandy loam (SL), silt and peat) containing composted onion waste (waste) (50% incorporation). Values are the mean of 30 replicate pots.

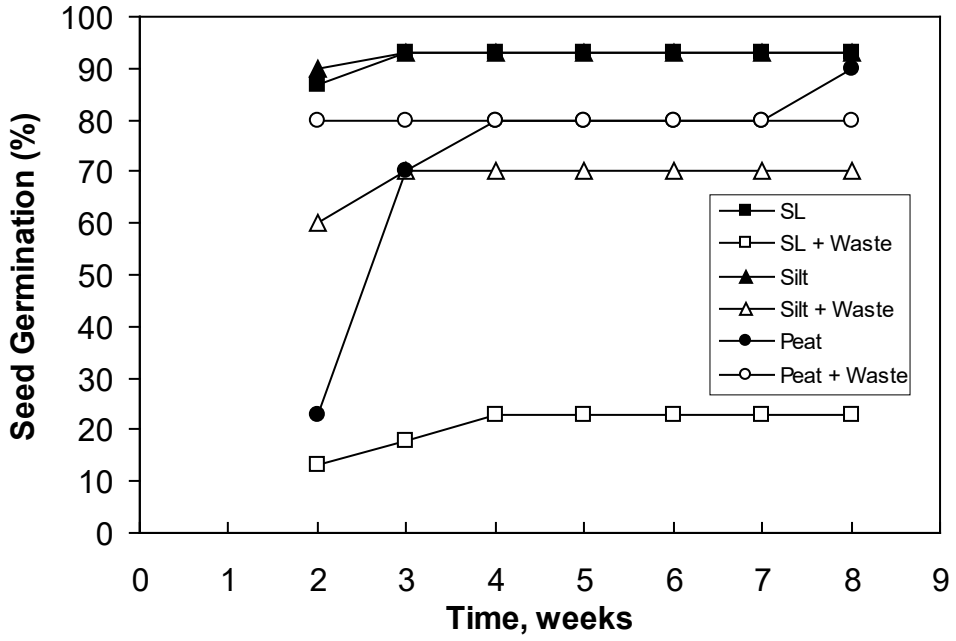

Figure 21
Germination of onion seed (Pot Bioassay 2) in 3 soil types (sandy loam (SL), silt and peat) containing composted onion waste (waste) (50% incorporation). Values are the mean of 30 replicate pots.

Seedling Pot Bioassay 1

The results of pot bioassay 1 using 4 week old onion seedlings are presented in Figure 22. The seedlings growing in the sandy loam and silt soils were exposed to the inoculated growing media for 5 weeks before any disease was detected. Disease was detected in the peat soil after 6 weeks. The presence of the composted waste delayed the onset of disease in all 3 soil types. Similar to the seed pot bioassays, very good disease control was achieved in the peat soil. Percentage infection of plants in the peat + waste treatment was approximately one sixth of that in the peat soil alone. There was no disease control in the silt soil. There was also no disease control in the sandy loam soil although percentage infection of the control plants (soil alone) was low. No disease was detected in the three soil types in the uninoculated pots.

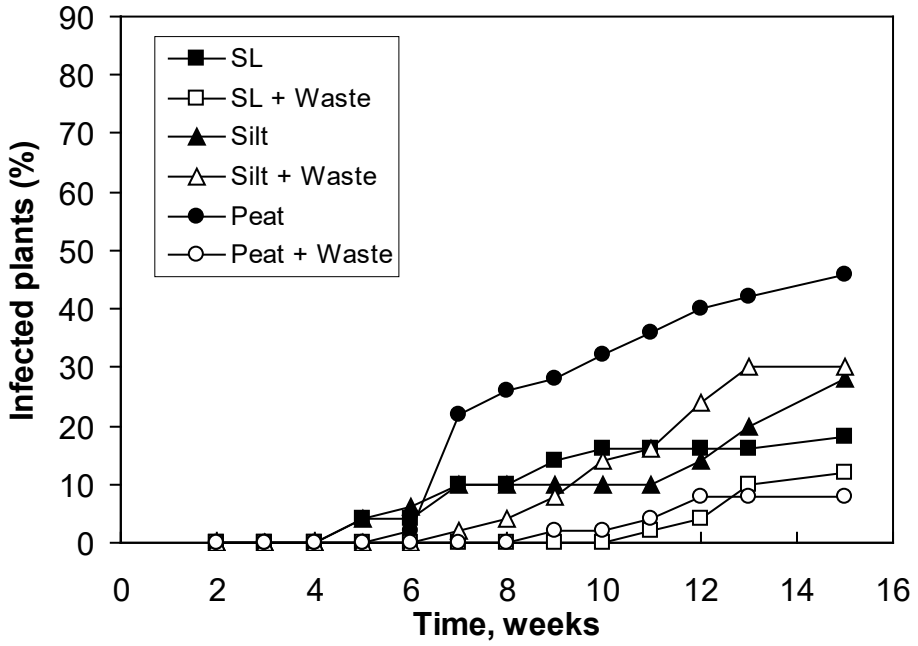

Figure 22

Onion plants (%) infected with *Allium* white rot in 3 soil types (sandy loam (SL), silt and peat) containing composted onion waste (waste) (50% incorporation rate) inoculated with 3 sclerotia/g of mixture. Values are the mean of 50 replicate pots.

Seedling Pot Bioassay 2

The results of the second pot bioassay using 4 week old onion seedlings are presented in Figure 23. Similar to seedling pot bioassay 1, the presence of the composted waste delayed the onset of disease in the peat and sandy loam soils. Very good disease control was achieved in the peat soil with the waste incorporation. Percentage infection of the plants in the peat + waste treatment was less than half that in peat soil alone. There was no disease control in the silt or sandy loam soils although percentage infection of the control plants (soil alone) was low. No disease was detected in the three soil types in the uninoculated pots.

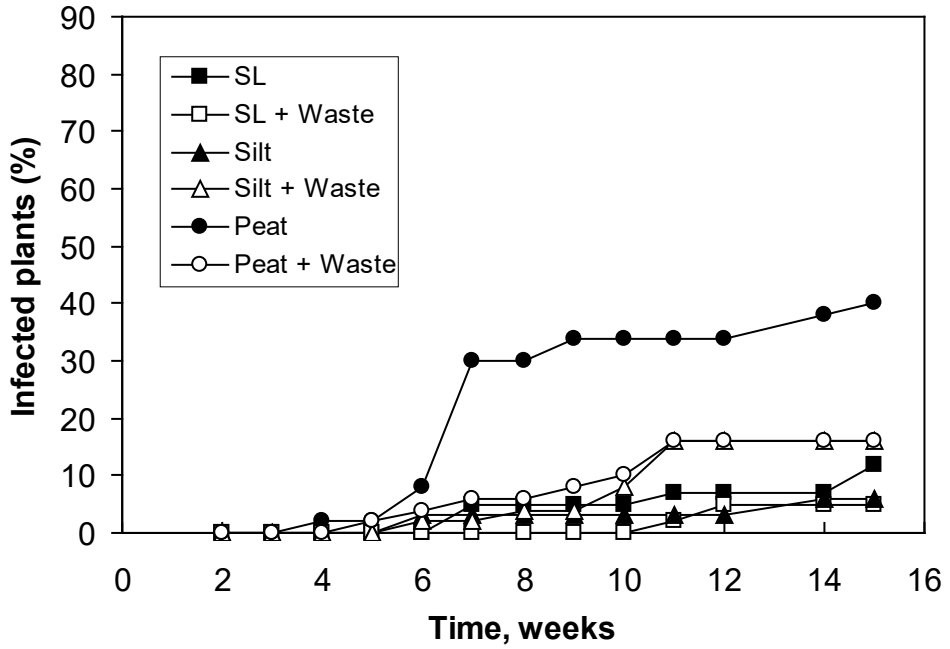

Figure 23

Onion plants (%) infected with *Allium* white rot in 3 soil types (sandy loam (SL), silt and peat) containing composted onion waste (waste) (50% incorporation rate) inoculated with 3 sclerotia/g of mixture. Values are the mean of 50 replicate pots.

Test for Phytotoxicity

After two weeks exposure to the treatments there was no obvious difference between the plants in the control (soil alone) and test (soil + waste) treatments, with the plants in all 3 soil types in good condition. By the third week of the bioassay the test plants were visually smaller than the control plants. After 4 weeks, the difference in size between the control and test plants was still apparent visually, and evident in the plant lengths and fresh weights recorded at harvest (Table 13). The plants in all 3 soil types with the onion compost incorporation were significantly smaller than those in the soils alone. Root development in the soil + waste treatments was also poor compared with the plants in soil alone. In addition, the tips of the leaves of the plants in all the soil + waste treatments were dead. There were no plant deaths in any of the treatments.

Table 13

Plant length (cm) from base of bulb to tip of longest leaf, and fresh weight (g) of 8 week old onion plants grown in 3 soil types (sandy loam, silt and peat) containing composted onion waste (50% incorporation rate). Values are the mean of 30 replicates. $P<0.05$. Waste = composted onion waste.

Treatment	Plant length (cm)	Fresh Weight (g)
Sandy loam	35.8 ± 0.60	28.0 ± 2.67
Sandy loam + waste	28.5 ± 0.53*	13.0 ± 1.07*
Silt	37.4 ± 0.43	28.0 ± 0.47
Silt + waste	26.0 ± 0.36*	9.7 ± 0.67*
Peat	33.7 ± 0.43	21.8 ± 1.09
Peat + waste	26.6 ± 0.45*	9.0 ± 0.33*

* Significantly different to control.

Larger-scale Controlled Composting of Vegetable Waste in Bulk Tunnels (Milestones 5.2, 5.4)

The different waste types composted well in the bulk tunnels with no unpleasant odours produced outside the tunnels during the composting period. Run-off collected was minimal in comparison to the volume of waste composted (Table 14). A large reduction in the volume of the salad onion and broccoli + sweetcorn wastes was noted within 24 hours of commencing composting. At the end of the composting period these wastes had visibly reduced in volume by *c.* 50%. This visual assessment was confirmed by measurement (Table 14). The weight of the waste also reduced during composting. Weight loss varied with the type of waste, ranging from 16-50% (Table 14).

Table 14

Weight loss (%), volume loss (%) and run-off (L tonne^{-1}) from vegetable waste composted for 7 days at 50 ºC in 6 or 20 tonne capacity bulk tunnels.
- = not determined.

Vegetable Waste	Initial Weight of Waste (kg)	Weight Loss (%)	Initial Volume of Waste (m^3)	Volume Loss (%)	Volume of run-off (L tonne^{-1})
Salad onion + straw	2475	50	-	-	-
Onion peelings + shale (1)	4131	16	-	-	26
(2)	5000	-	-	-	18
(3)	10,000	-	-	-	-
(4)	2934	17	17	68	-
Crushed whole onions + shale	5750	17	17	50	-
Broccoli + sweetcorn + onion shale	1660	37	9	46	-

Field Trials (Milestones 5.2, 5.4, 6.2, 6.4)

1. Salad Onion Waste

Crop 1

The results for the percentage recovery, soft sclerotia and germination of sclerotia retrieved after 3 months burial in 50% salad onion + straw waste (composted) are detailed in Table 15. Recovery of sclerotia from the control and test plots was similar. The presence of the waste had no effect on the viability of the sclerotia at this stage of the trial.

Table 15

Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **3 months** burial in a field site with composted salad onion + straw waste applied and incorporated to a 50% rate (Test). Values are the mean of 10 replicate bags each containing 100 sclerotia. P>0.05.

Treatment	Recovery	Soft	Germination
Control	92	1.9 ± 0.81	95.0 ± 1.97
Test	88	0.4 ± 0.22	94.3 ± 1.33

The results for the percentage recovery, soft sclerotia and germination of sclerotia retrieved at harvest (10 months burial) are detailed in Table 16. Recovery of sclerotia from the test plot was slightly lower than from the control plot. Similar to the results after 3 months burial, the compost application had no effect on the viability of the hard sclerotia retrieved from the test plot.

Table 16

Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved at harvest after **10 months** burial in a field site with composted salad onion + straw waste applied and incorporated at a 50% rate (Test). Values are the mean of 10 (control) and 6 (test) replicate bags each containing 100 sclerotia. P>0.05.

Treatment	Recovery	Soft	Germination
Control	92	2.3 ± 0.92	99.4 ± 0.40
Test	83	1.3 ± 0.61	98.8 ± 1.17

There was a small difference in the number of healthy and diseased plants sampled from the control and test plots (Table 17). Fewer plants infected with *Allium* white rot (AWR) were sampled from the compost amended plot. Observation of the field trial at harvest revealed poor emergence of the onions, particularly in the control plot. The control and test plots had no weed control during the growing season and this possibly contributed to the poor emergence observed.

Table 17
Number of healthy and diseased plants sampled from the control and test plots. Sample size = 100 per plot. AWR = *Allium* white rot.

Treatment	Healthy	AWR	Diseased – not AWR
Control	52	29	19
Test	57	25	18

The presence of the waste in the test plot had an effect on the growth of the onions. The plants in the test plot were significantly larger ($P<0.01$) than those in the control plot (Table 18).

Table 18
Length of plants (cm) in control and test plots from base of bulb to tip of longest leaf. AWR = *Allium* white rot. Values are the mean ± SE. $P<0.01$.

Treatment	Healthy	AWR	Diseased – not AWR
Control	13.6 ± 0.33	13.8 ± 0.48	13.8 ± 0.68
Test	18.9 ± 0.5*	19.5 ± 0.92*	17.8 ± 0.75*

* Significantly different to control

Crop 2

Similar to the results from crop 1, there was a difference in the number of diseased plants sampled from the control and test plots (Table 19). The sample from the control plot had more than twice as many AWR infected plants as the sample from the test plot, although the number of infected plants sampled was low. Unlike crop 1, there was good emergence of the onions in both the control and test plots. There was no difference in size between the plants in the control and test plots although the total fresh weight of the test plants was slightly heavier than the control plants (Table 19).

Table 19

Number of AWR infected plants, mean plant length (from base of bulb to tip of longest leaf) (cm) and total fresh weight (g) of 100 onion plants sampled from the control and test plots. AWR = *Allium* white rot.

Treatment	AWR plants	Mean Plant Length (cm)	Total Fresh Weight (g)
Control	14	26.2	1015.6
Test	6	27.6	1158.9

2. Bulb Onion Waste

(a) HRI-Kirton

The codes for the various treatments applied to plots of land at HRI-Kirton are detailed in Table 20.

Table 20
Treatment codes for field trial at HRI-Kirton.

	Onion Planting (2001)	**Date of Compost Application**	**Compost**
B	April	August 2000	Fresh
C	May	April 2001	Stored
D	May	April 2001	Fresh
E	May	August 2000	Stored
F	May	August 2000	Fresh
G	April	Untreated control	None
H	May	Untreated control	None
J	April	Folicur dipped sets	None
K	May	Folicur dipped sets	None

(I) Retrieval of sclerotia buried in plots

Compost applied in August 2000

The results for the percentage recovery, soft sclerotia and germination of sclerotia retrieved after 2 months burial in 50% fresh or stored composted onion waste are detailed in Table 21. Recovery of sclerotia from the compost amended (treatments B, E and F), untreated control (treatment G) and Folicur treated (treatment J) plots was similar. The presence of the waste had no effect on the viability of the sclerotia at this stage of the trial.

Table 21
Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **2 months** burial in a field site at HRI-Kirton with composted bulb onion + shale waste applied and incorporated to a 50% rate. Values are the mean of six replicate bags each containing 100 sclerotia. P>0.05.

Treatment	Recovery	Soft Sclerotia	Germination
B	90	3.3	89.5
E	97	1.7	97.3
F	100	0.5	99.5
G	96	1.1	96.1
J	99	0.8	98.8

The results for the percentage recovery, soft sclerotia and germination of sclerotia retrieved after 8 months burial in 50% fresh or stored composted onion waste are detailed in Table 22. Recovery of sclerotia from the various treatment plots was similar. The percentage of soft sclerotia retrieved from the control plots (treatments G and J) was very low. The stored compost applied to plots in August with sets planted in May (treatment E) significantly increased the percentage of soft sclerotia retrieved. A number of soft sclerotia were also retrieved from the plots with fresh compost applied (treatments B and F) but due to much variability within the population of sclerotia sampled, these treatments were not significantly different from the controls. Similar to the results after 2 months burial, the treatments had no effect on germination of sclerotia retrieved.

Table 22
Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **8 months** burial in a field site at HRI-Kirton with composted bulb onion + shale waste applied and incorporated to a 50% rate. Values are the mean of six replicate bags each containing 100 sclerotia.

Treatment	Recovery	Soft Sclerotia	Germination
B	72	17.8	99.5
E	74	39.0*	99.0
F	82	6.3	99.5
G	77	0.4	99.8
J	85	0.5	100.0
		LSD = 21.1	**P>0.05**

* Significantly different to control.

The results for the percentage recovery, soft sclerotia and germination of sclerotia retrieved at onion harvest in August (12 months burial) are detailed in Table 23. There was a similar percentage recovery of sclerotia from the compost amended (treatments B, E, and F) and the control plots (treatments G, J, H and K). The fresh compost applied in August with sets planted in May (treatment F) reduced the percentage germination of retrieved sclerotia compared with the control. The presence of the composted waste did not increase the percentage of soft sclerotia retrieved from any of the compost amended plots (treatments B, E and F) although a high percentage of soft sclerotia was retrieved from the control treatments (H and K).

Table 23

Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **12 months** burial in a field site at HRI-Kirton with composted bulb onion + shale waste applied and incorporated to a 50% rate. Values are the mean of six replicate bags each containing 100 sclerotia. $P<0.05$.

Treatment	Recovery	Soft Sclerotia	Germination
B	72	18.3	97.8
E	63	19.3	98.9
F	75	8.3*	96.7*
G	83	11.5	98.2
H	69	36.2	97.8
J	64	8.0	98.0
K	72	31.2	100.0

* Significantly different to control.

Compost applied in April 2001

The results for the percentage recovery, soft sclerotia and germination of sclerotia retrieved after 2 months burial in 50% fresh or stored composted onion waste are detailed in Table 24. Recovery of sclerotia from the untreated (treatment H) and the Folicur treated (treatment K) plots was higher than from the compost amended plots (treatments C and D). The stored and the fresh compost applied to plots in April with sets planted in May (treatments C and D) significantly increased the percentage of soft sclerotia retrieved. Similar to the plots with the compost applied in August 2000 (Table 21), the presence of the compost had no effect on the germination of sclerotia retrieved after 2 months burial.

Table 24
Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **2 months** burial in a field site at HRI-Kirton with composted bulb onion + shale waste applied and incorporated to a 50% rate. Values are the mean of six replicate bags each containing 100 sclerotia.

Treatment	Recovery	Soft Sclerotia	Germination
C	63	46.3*	94.2
D	65	50.8*	89.8
H	92	5.3	96.7
K	74	9.2	93.3
		LSD = 18.6	**P>0.05**

* Significantly different to control.

The results for the percentage recovery, soft sclerotia and germination of sclerotia retrieved after 4 months burial in 50% fresh or stored composted onion waste are detailed in Table 25. Recovery of sclerotia from the compost amended plots (treatments C and D) was lower than that from the untreated (treatment H) and Folicur treated (treatment K) plots. In contrast to the results after 2 months burial, the compost treatments had no effect on the viability of sclerotia retrieved. A high percentage of soft sclerotia was however retrieved from the control plots (treatments H and K). This, in conjunction with the lower recovery of sclerotia from the composted amended plots, may explain why no difference between the control and test treatments was detected.

Table 25
Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **4 months** burial in a field site at HRI-Kirton with composted bulb onion + shale waste applied and incorporated to a 50% rate. Values are the mean of six replicate bags each containing 100 sclerotia. P>0.05.

Treatment	Recovery	Soft Sclerotia	Germination
C	53	32.0	96.7
D	39	34.7	97.5
H	69	36.2	97.8
K	72	31.2	100.0

The results for sclerotia retrieved at onion harvest in September (4.5 months burial) are detailed in Table 26. Similar to the results after 4 months burial, the presence of the waste had no effect on the viability of sclerotia retrieved. A high percentage of soft sclerotia was also retrieved from the control plots (treatments H and K) and percentage recovery from the compost amended plots (treatments C and D) was lower than from the control plots.

Table 26

Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **4.5 months** burial in a field site at HRI-Kirton with composted bulb onion + shale waste applied and incorporated to a 50% rate. Values are the mean of six replicate bags each containing 100 sclerotia. P>0.05.

Treatment	Recovery	Soft Sclerotia	Germination
C	48	32.3	98.0
D	45	52.2	96.8
H	66	48.8	95.8
K	70	48.9	97.6

(II) Emergence of sets

The emergence of sets planted in April 2001 (variety Sturon) over a 2 week period in plots with compost applied in August 2000 is shown in Figure 24. The presence of the fresh composted waste (treatment B) had no detrimental effect on emergence. At the first emergence count slightly fewer plants had emerged in the composted amended plots compared with the untreated control (treatment G) but more than those treated with Folicur (treatment J). Emergence followed a similar trend at the second count and at the final count there was slightly higher emergence in the compost treatment than in the untreated control and Folicur treatment.

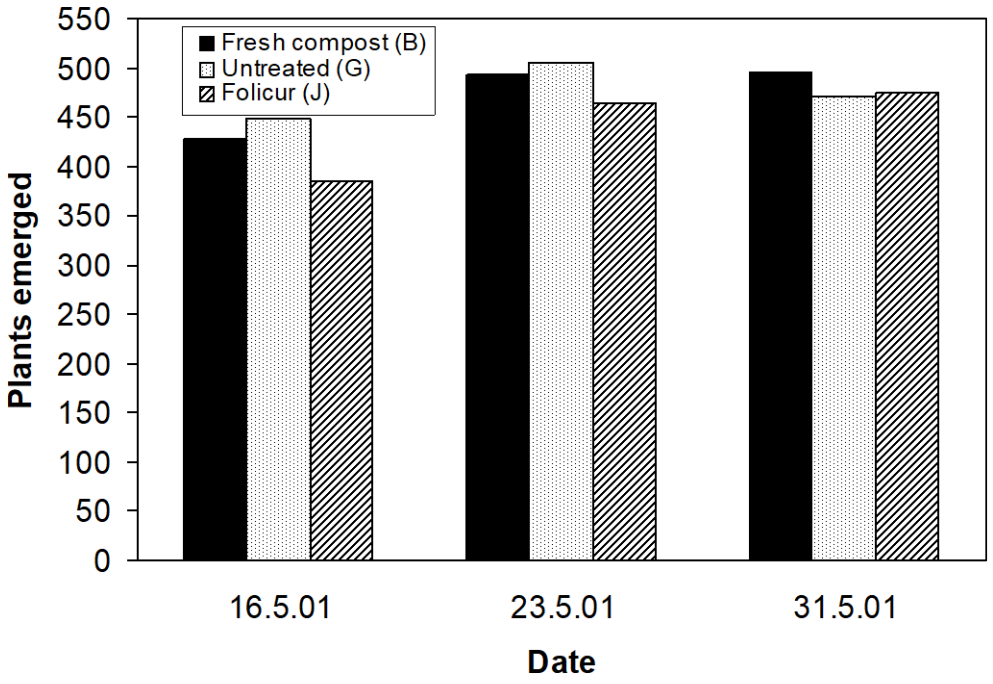

Figure 24
Emergence of onion sets (variety Sturon) planted in April 2001 in plots with fresh compost applied and incorporated at a 50% rate in August 2000.

The emergence of the sets planted in May 2001 (variety Rijnsburger) over a 4 week period in plots with compost applied in April 2001 is shown in Figure 25. The presence of the composted waste (treatments C and D) reduced emergence compared with the untreated control (treatment H) and Folicur treated sets (treatment K). Emergence in the fresh compost treatment (treatment D) was better than in the stored compost treatment (treatment C), and by the third count, emergence in the fresh compost was similar to that in the untreated control and Folicur treatment.

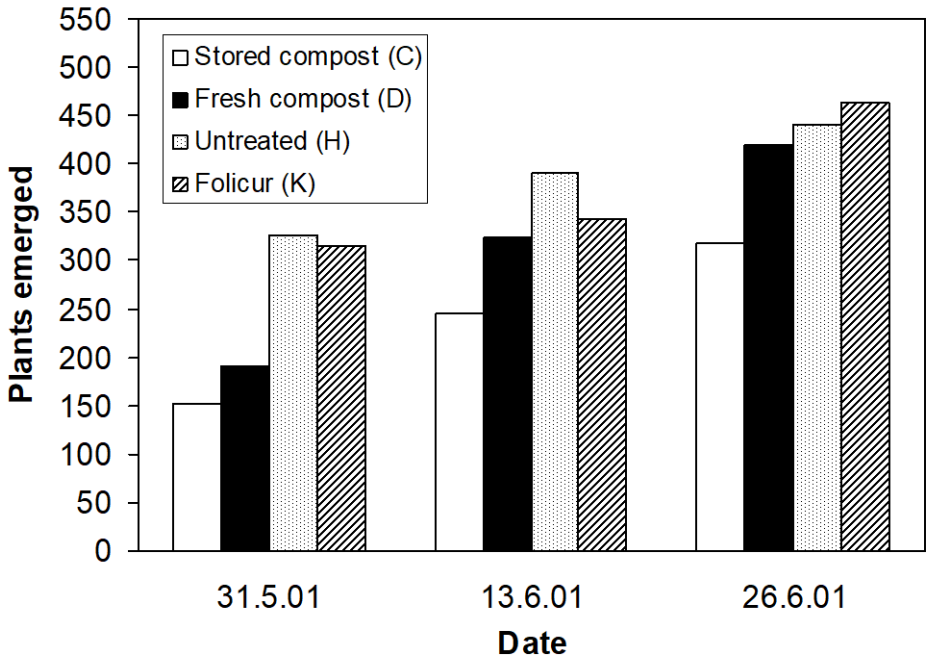

Figure 25
Emergence of onion sets planted in May 2001 (variety Rijnsburger) in plots with stored and fresh compost applied and incorporated at a 50% rate in April 2001.

The emergence of the sets planted in May 2001 (variety Rijnsburger) over a 4 week period in plots with compost applied in August 2000 is shown in Figure 26. The trend in emergence followed a similar pattern to the Rijnsburger sets planted in May with composted waste applied one month earlier in April 2001 (Figure 25). Emergence in the untreated control (treatment H) was slightly higher than in the two compost treatments (treatments E and F), with higher emergence in the fresh compost (treatment F) than in the stored (treatment E).

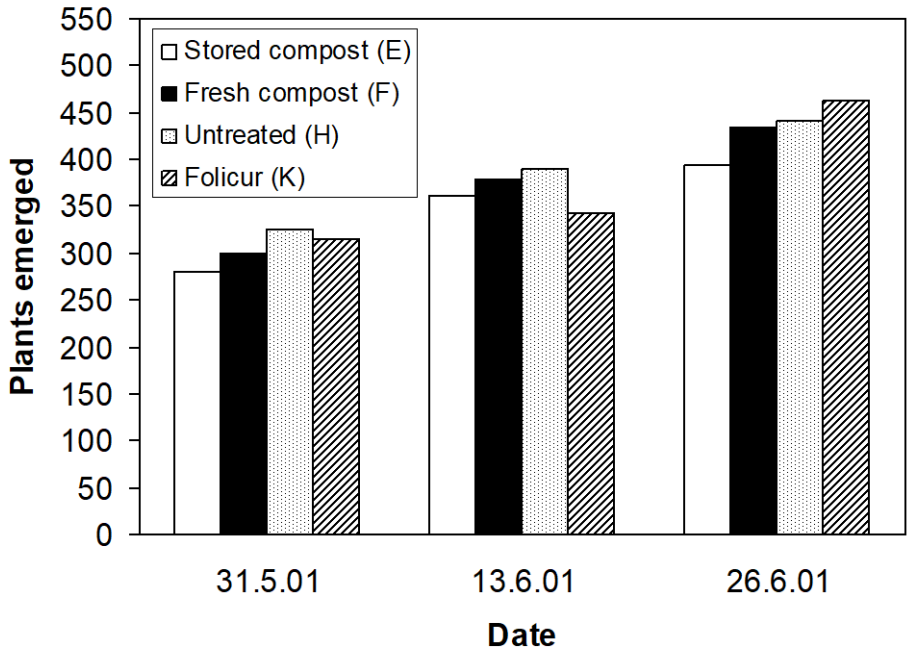

Figure 26
Emergence of onion sets planted in May 2001 (variety Rijnsburger) in plots with stored and fresh compost applied and incorporated at a 50% rate in August 2000.

(II) Allium *white rot assessment*

The results of the assessments made on the plots with fresh compost applied in August 2000 and sets planted in April 2001 (onion variety = Sturon) are shown in Figure 27. At the first assessment, there were more diseased plants in the compost amended plots (treatment B) than in the untreated control (treatment G) and Folicur treatment (treatment J). In contrast, there were fewer diseased plants recorded in the compost treatment than in the untreated control at the second and third assessments although infection levels were still high. The Folicur treatment provided the best control.

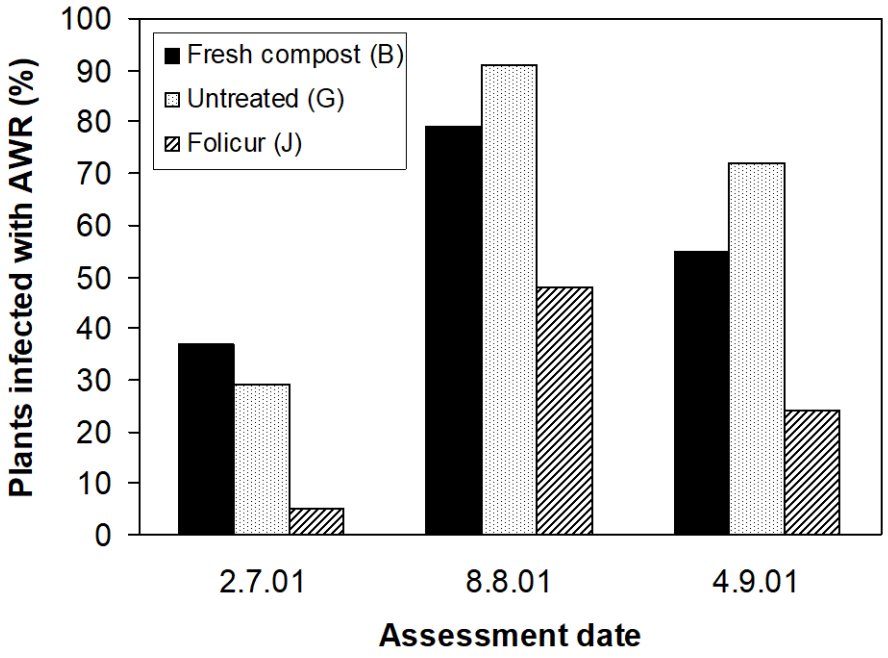

Figure 27
Onion plants (%), variety Sturon, planted in April 2001 in plots with fresh compost applied in August 2000, infected with AWR throughout the growing season.

The results of the AWR assessments made on the plots with stored and fresh compost (treatments C and D respectively) applied in April 2001 and sets planted in May 2001 (onion variety = Rijnsburger) are shown in Figure 28. With the exception of the first assessment where a small percentage of plants were infected in the fresh compost treatment (treatment D), the compost treatments provided similar level of control to the Folicur treatment (treatment K). There were fewer diseased plants recorded in the compost treatments at the second and third assessment dates than in the untreated control (treatment H), with the fresh compost providing slightly better control than the stored.

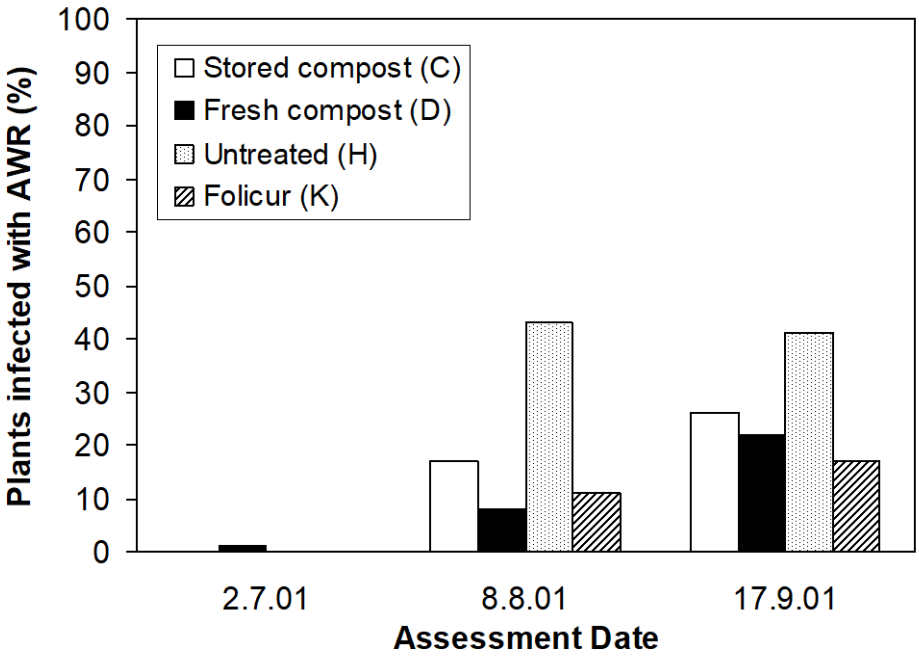

Figure 28
Onion plants (%), variety Rijnsburger, planted in May 2001 in plots with stored and fresh compost applied in April 2001, infected with AWR throughout the growing season.

The results of the AWR assessments made on the plots with stored and fresh compost (treatments E and F respectively) applied in August 2000 and sets planted in May 2001 (onion variety = Rijnsburger) are shown in Figure 29. No disease was recorded in any of the treatments at the first assessment date. At the second assessment, fewer diseased plants were recorded in the compost treatments (treatments E and F) than in the untreated control (treatment H). In addition, disease levels in the fresh compost treatment (treatment F) were similar to the Folicur treatment (treatment K). Similar to the second assessment, the fresh compost treatment was shown to be as effective in controlling AWR as the Folicur treatment at the final assessment.

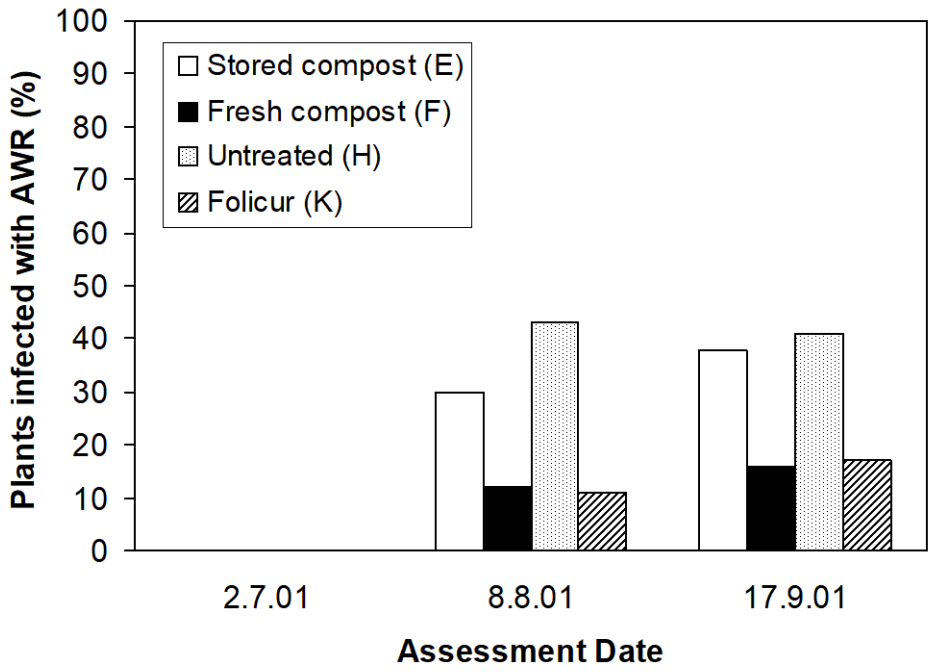

Figure 29
Onion plants (%), variety Rijnsburger, planted in May 2001 in plots with stored and fresh compost applied in August 2000, infected with AWR throughout the growing season.

(IV) Onion yield

The total healthy yield of onions from each of the treatments at harvest is shown in Figure 30. The Folicur treated sets gave the highest yield (treatments J and K). The yield with the fresh compost (treatments D and F) was higher than with the stored compost (treatments C and E) for the Rijnsburger sets. A higher yield was recorded for the Rijnsburger variety than from the Sturon sets for comparable treatments. With the exception of treatment F (fresh compost applied in August 2000 with sets planted in May 2001), onion yield was lower in the compost treatments (treatments B, C, D, E) than in the appropriate untreated controls (treatments G and H).

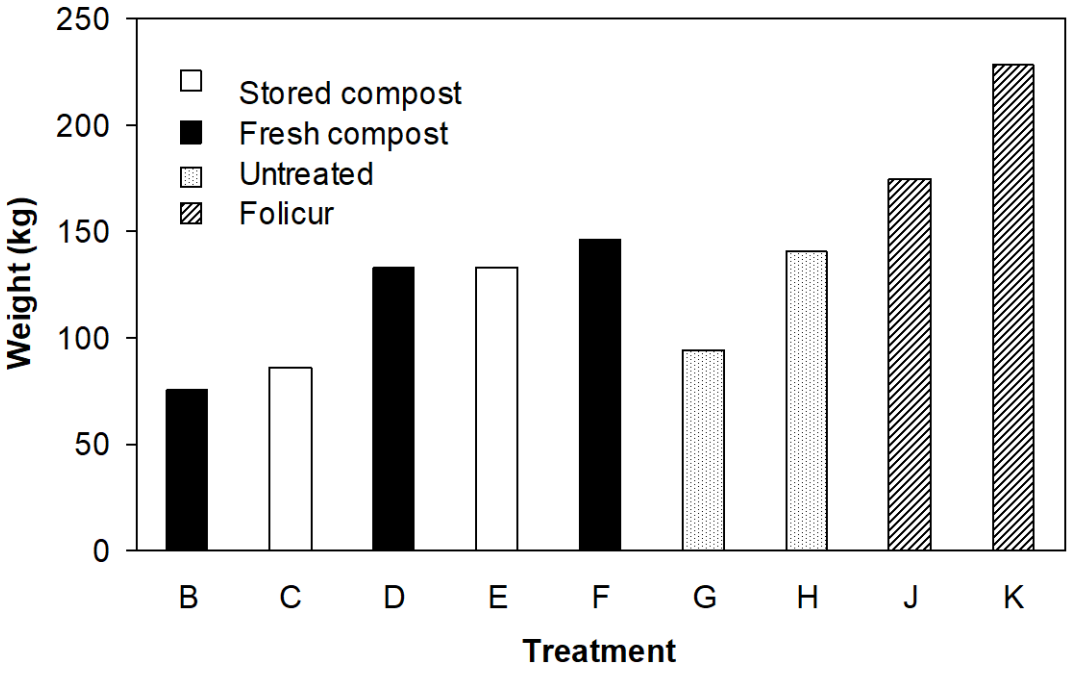

Figure 30
Total healthy onion yield (kg) from the various treatments recorded at harvest.

With the exception of treatment B in which most bulbs were <40 mm in size, the largest percentage of bulbs in all treatments were 40-60 mm in size. Figure 31 shows the percentage of bulbs >40 mm in size. With the exception of treatments B and G (untreated control), there was a similar percentage of bulbs of this size across the treatments.

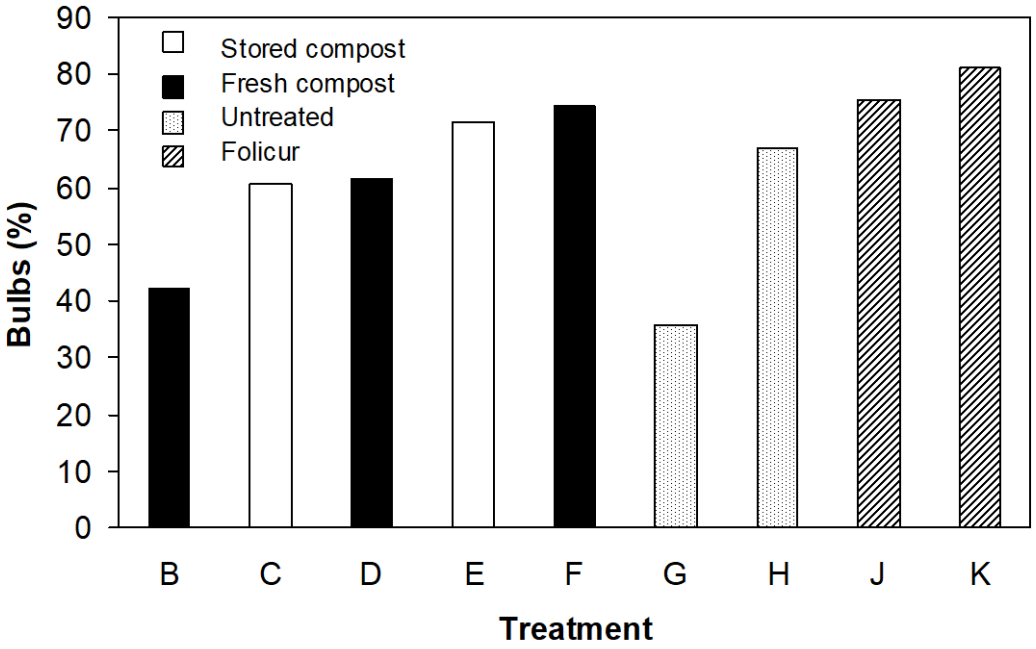

Figure 31
Onion bulbs (%) > 40 mm in size in the various treatments at harvest.

The percentage of plants infected with *Allium* white rot and other rots at harvest is shown in Figures 32 and 33 respectively. The Folicur treatments provided the best control for both AWR and other rots. Less disease was recorded in the compost treatments (treatments B, C, D, E, F) than in their respective untreated controls (treatments G and H). The fresh compost treatments (treatments D and F) provided better control than the stored (treatments C and E) with the Rijnsburger variety. In addition, less disease was recorded in the Rijnsburger sets than with the Sturon variety (treatments B, G and J).

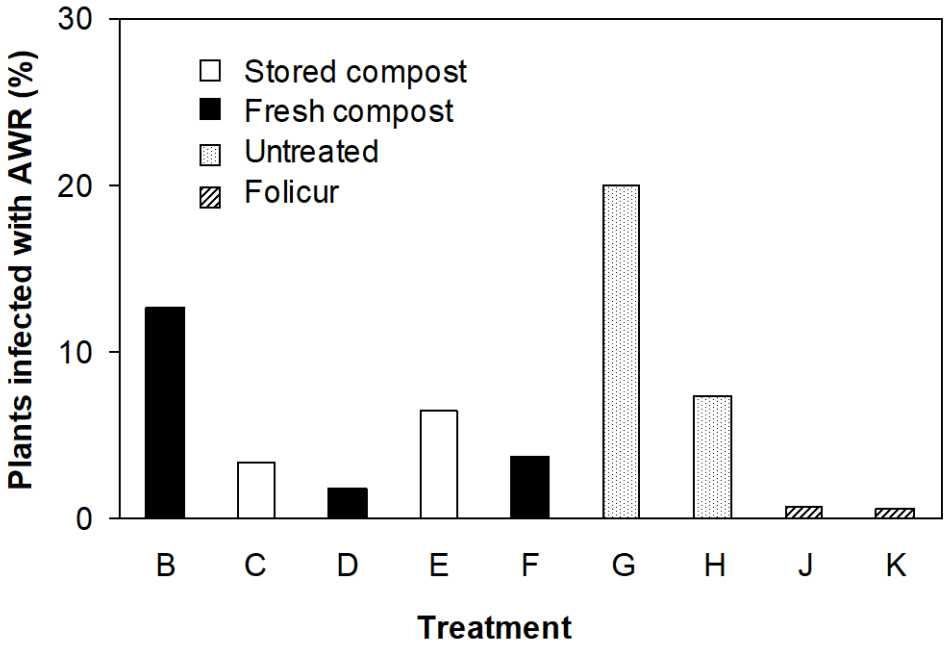

Figure 32
Plants infected with *Allium* white rot (%) in the various treatments at harvest.

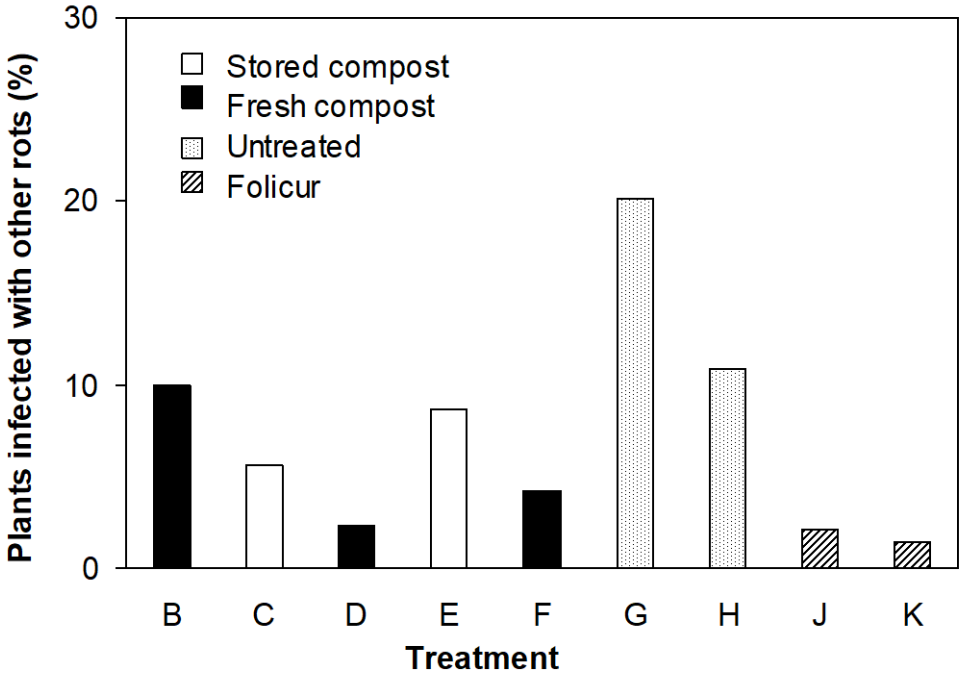

Figure 33
Plants infected with rots other than *Allium* white rot (%) in the various treatments at harvest.

(b) Goldwood (Moulton) Limited

This field trial was cancelled due to bad weather conditions which prevented application of the composted waste to the land.

(c) Bedfordshire Growers Limited

Similar to the results with the salad onion waste, the presence of the composted bulb onion waste had no effect on the viability of the sclerotia retrieved from the field trial after 3 months burial (Table 27). Recovery of sclerotia from the test plot was lower than from the control plot (Table 27).

Table 27

Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **3 months** burial in a field site with composted bulb onion + shale waste applied and incorporated to a 50% rate (Test). Values are the mean of 10 (control) and 9 (test) replicate bags each containing 100 sclerotia. P>0.05.

Treatment	Recovery	Soft	Germination
Control	77	1.4 ± 0.47	97.2 ± 1.02
Test	71	15.67 ± 7.12	96.6 ± 1.90

In addition, no significant effect of the compost incorporation on sclerotia viability was recorded after 6 months burial (Table 28). Recovery of sclerotia from the test plot was lower than from the control plot (Table 28).

Table 28

Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **6 months** burial in a field site with composted bulb onion + shale waste applied and incorporated to a 50% rate (Test). Values are the mean of 10 (control) and 9 (test) replicate bags each containing 100 sclerotia. P>0.05.

Treatment	Recovery	Soft	Germination
Control	72	11.2 ± 4.52	99.0 ± 0.73
Test	63	23.7 ± 10.80	100.0 ± 0

At harvest the plants in both the control and test plots were in good condition with no signs of phytotoxicity. There was no obvious difference between the plants in the two plots although when weighed, the control plants were slightly heavier than those from the test plot (Table 29). No AWR was recorded in any of the plants sampled from either the control or test plots.

Table 29
Total fresh weight (g) of whole plants (roots, bulb and leaves) sampled from the control and test plots.

Treatment	Plant weight (100 plants)
Control	5585.6
Test	5367.9

3. Sweetcorn, Broccoli + Onion Shale Waste

Similar to the results from the trial using the composted bulb onion waste in Bedfordshire, the presence of the composted sweetcorn, broccoli + onion shale waste had no effect on the viability of the sclerotia retrieved from the field trial in Cambridgeshire after 5 and 6 months burial (Tables 30 and 31). A high percentage of soft sclerotia were retrieved from the test plot at both sampling dates. A high percentage of soft sclerotia was however also retrieved from the control plot, particularly at the 6 month sampling. This resulted in no significant difference between the control and test treatments when otherwise a difference would have been expected. Recovery of sclerotia from the test plot was lower than from the control plot. This may partly explain why no difference between the plots with respect to sclerotia viability was detected.

Table 30
Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **5 months** burial in a field site with composted sweetcorn, broccoli + onion shale waste applied and incorporated at a 50% rate (Test). Values are the mean of 10 replicate bags each containing 100 sclerotia. $P<0.05$.

Treatment	Recovery	Soft	Germination
Control	67	21.5 ± 2.83	91.9 ± 1.84
Test	49*	36.2 ± 6.31	94.9 ± 2.62

* Significantly different to control

Table 31
Recovery (%), soft sclerotia (%) and germination (%) of sclerotia of *S. cepivorum* retrieved after **6 months** burial in a field site with composted sweetcorn, broccoli + onion shale waste applied and incorporated to a 50% rate (Test). Values are the mean of 6 (control) and 10 (test) replicate bags each containing 100 sclerotia. P>0.05.

Treatment	Recovery	Soft	Germination
Control	60	62.0 ± 10.73	86.2 ± 5.94
Test	50	52.9 ± 4.65	88.1 ± 4.36

Similar to the field trial in Bedfordshire, at harvest the plants in both the control and test plots were in good condition with no signs of phytotoxicity. There was no obvious difference between the plants in the two plots although when weighed, the control plants were slightly heavier than those from the test plot (Table 32). No AWR was recorded in any of the plants sampled from either the control or test plots.

Table 32
Total weight (g) of whole plants (roots, bulb and leaves) sampled from the control and test plots.

Treatment	Plant weight (100 plants)
Control	11409.9
Test	11239.0

Discussion

Milestones 1.1, 1.2 – The moisture contents of the wet onion, *Brassica* and carrot wastes were *c.* 85-93% and hence composting these materials as individual wastes was impractical due to the run-off which would have been produced. Onion shale is readily available from pack houses and therefore was the ideal material to mix with the other wastes to decrease the moisture content. A temperature of 50 ºC for a period of 7 days was initially chosen to compost the waste mixtures in flask-scale experiments as this temperature is commonly reached in composting materials. Waste prepared to an 80% moisture content and composted under these conditions was soft and wet in texture, although the vegetable wastes could still be recognised, and produced little run-off and unpleasant odours during composting.

The pH of waste composts is generally too high for use as peat alternatives. However, the composted onion waste had a very low pH and hence may have potential as a suitable alternative to peat.

Milestone 2.1 – Composting onion waste infested with the pathogens of interest for 7 days at 50 ºC destroyed sclerotia of *S. cepivorum* and resting spores of *O. brassicae*, and reduced the viability of propagules of *F. oxysporum*. These conditions also destroyed 5 day old onion fly larvae and the nematode, *Steinernema feltiae*, present in the waste. Vegetable waste composted for 7 days at 50 ºC should therefore be free of these pathogens and pests and hence safe to apply to land.

There was no clear trend on the effect of holding sclerotia in the nozzles of flasks incubated at different temperatures except the presence of a large number of contaminants. The sclerotia had been surface sterilised prior to plating on to growth medium and therefore the contaminants must have come from within the sclerotia. These were not present on the control sclerotia suggesting the volatiles released from the composting onion waste had weakened the test sclerotia allowing colonisation by other fungi. These fungi may be potential biocontrol agents and could be used in future studies.

Milestones 3.1, 3.2 – The GC-MS analysis of the onion waste samples revealed composting reduced the di-propyl disulphide (dpds) content compared with fresh waste (Table 10). There was however no great difference in the composition of the volatiles analysed between the composts produced at the two temperatures (42 ºC and 54 ºC) and incubation periods (3 and 7 days). Interestingly, when these composts were used in the onion waste pot bioassay in sandy loam, the composted onion waste treatments were generally more effective in reducing viability of the sclerotia than the fresh raw waste treatment. The higher temperature compost was the most effective treatment in reducing sclerotia viability at the three rates of incorporation. The reason for this difference is unclear and may be the result of an increased level of degradation of the waste at the higher temperature leading to breakdown and release of other compounds not analysed.

Similar to the results of the onion waste pot bioassay, the composted *Brassica* and carrot waste treatments in sandy loam were more effective in reducing sclerotia viability than the fresh raw waste, with the 50% rate of the wet carrot waste being the

most effective treatment. The effect of the three waste types on the viability of sclerotia in sandy loam soil was found to be dependent on the length of exposure and the amount of waste present. In general, the longer the sclerotia were in contact with the waste and the higher the rate of waste incorporation, the greater the reduction in viability. A similar trend was observed in the onion and other vegetable waste pot bioassay in the silt soil with the 50% rates of the onion peelings and broccoli florets being the most effective treatments, although the raw waste was more effective than the composted. In the peat soil pot bioassay, the raw and composted wastes were equally effective. Similar to the sandy loam and silt soils pot bioassays, the effect of the vegetable wastes on sclerotia in the peat soil was dependent on the rate of incorporation, with the 50% rates of the onion peelings and broccoli florets being the most effective treatments.

The increase in percentage soft and reduction in germination of sclerotia in the presence of the waste ranged from *c.* 18-65% and *c.* 22-80%, respectively, in the various pot bioassays. The onion peelings and broccoli stalks were consistently the most effective vegetable waste treatments in the three soils. The range in the effect of the wastes on viability presumably, therefore, reflects differences between soil types and their interaction with the pathogen.

Temperature Effects on Glasshouse Studies – The temperatures recorded in the glasshouse were higher than those in the field throughout the 9 months duration of the comparative pot experiment in the two environments. This difference in temperature between the glasshouse and field may explain the generally higher percentage of soft sclerotia retrieved from the glasshouse pots (Table 11(a)) compared with the field (Table 11(b)). The difference in temperature however did not seem to influence the effectiveness of the two treatments, in terms of soft sclerotia, within the two environments. Only two composted waste treatments within each environment increased the percentage of soft sclerotia retrieved relative to the soil alone, with no trend in effect.

The results for the germination of retrieved sclerotia suggest that the elevated temperature in the glasshouse may have increased the speed of the effect of the composted waste although, similar to the soft sclerotia retrieved, there was no clear trend in effect. The presence of the composted waste reduced germination of retrieved sclerotia after 1, 2 and 3 months burial in the silt soil in the glasshouse pots, but had no effect on sclerotia which were buried for 6 or 9 months. In contrast, a reduction in germination was recorded for the sclerotia retrieved from the pots in the silt soil in the field after 6 months burial. Germination of sclerotia retrieved from the peat soil with composted onion waste was reduced after 3, 6 and 9 months burial in the pots in the glasshouse, whereas in the field an effect of the waste was only recorded after 2 months burial.

Milestone 4.2 – Good control of *Allium* white rot (AWR) with composted onion waste was achieved in all the pot bioassays with the peat soil. In general, the levels of disease in the control plants in the sandy loam and silt soils were low in comparison to those in the peat soil. Thus, any control effect of the compost treatments in the sandy loam and silt soils was difficult to detect. The exception to this was in seed pot bioassay 2 where a high level of infection was achieved in the sandy loam soil and no disease was detected in the presence of the waste in this soil. This suggests when

infection levels are high the presence of the composted waste has an effect on development of the disease in sandy loam soil. Each of the soils and the soil + waste mixtures received the same level of inoculum from the same stock of sclerotia in all four bioassays. Similar to the pot bioassays looking at the sclerotia stimulant activity of composted vegetable waste (Milestone 3.2), these results suggest that the behaviour of sclerotia differs between soil types. The peat soil would seem to be a conducive environment for the development of AWR whilst the sandy loam and silt soils are generally more suppressive to the disease.

In addition to the variability in disease levels observed between soils, there was variability within soils in the two seed pot bioassays. In seed pot bioassay 1, the level of infection in the peat soil alone was *c.* 80% whereas in seed pot bioassay 2 the level of infection was *c.* 45%. Similarly, in the sandy loam soil, levels of infection were *c.* 25% and 75% in seed pot bioassays 1 and 2 respectively. Both pot bioassays were carried out during the winter in a heated glasshouse and hence environmental conditions for the duration of the experiments were similar. The reason why different levels of infection were achieved is, therefore, unclear but variable infection levels with the same inoculum has been observed in other similar experiments on work looking at the biological control of AWR at HRI-Wellesbourne.

Seed germination in the seed pot bioassays was lower in the composted waste treatments than in the soils alone, especially in the silt and sandy loam soils. In addition, the results of the phytotoxicity pot bioassay indicated that composted onion waste incorporated at a 50% rate is phytotoxic to the growth of onion seedlings. As discussed under Milestone 6.4 below, this problem of phytotoxicity may be overcome by having a sufficient delay between compost application and onion planting.

Milestones 5.2, 5.4 – The flask-scale experiments in Milestone 1.2 identified the vegetable waste mixtures and composting conditions which minimised run-off and odours produced. These parameters were applied to composting vegetable waste on a large scale in bulk tunnels. The wastes in the bulk tunnels composted well under these conditions, with the volume of waste reducing by up to 68% and weight loss ranging from 4-50%. In addition, similar to the flask-scale experiments, the wastes in the bulk tunnels produced minimal run-off and no unpleasant odours.

Milestones 5.2, 5.4, 6.2, 6.4 – <u>Commercial Field Sites</u> In contrast to the results from the pot bioassays looking at the sclerotia stimulant activity of composted vegetable waste (Milestone 3.2), the presence of the composted vegetable waste had no significant effect on the viability of sclerotia retrieved from the three commercial field sites. It is not unusual for field trial results to differ from those obtained in glasshouse trials due to the variability in environmental conditions in the field although some effect throughout the course of the trials would have been expected. A number of the sclerotia viability assessments were made after onions had been sown/planted. The presence of these onions could have stimulated the sclerotia to germinate in the control plots. Indeed, a high percentage of soft sclerotia was retrieved from the control plot at the field trial in Cambridgeshire. In addition, recovery of the sclerotia from the test plots was generally lower than from the control plots. This may have been due to sclerotia germinating in the presence of the waste and hence were no longer present as sclerotia to retrieve from the bags. This may explain why no difference between treatments was detected when the results of the pot bioassays

suggested a difference would have been expected. Indeed, if the results of the three commercial field trials are combined, recovery of sclerotia from the compost amended plots was significantly lower ($P<0.005$) than from the control plots.

The actual rates of application of the composted waste varied between field trials: Bedfordshire = 27%; Cambridgeshire = 54%; and Kent = 16%. No AWR was recorded in either the control or test plots at the Bedfordshire and Cambridgeshire sites. There were no visible signs of phytotoxicity observed in the plants grown in the compost amended plots at these sites although the weights of the control plants were slightly heavier than the test. A level of disease control was achieved with the composted onion waste incorporation at the field trial in Kent, with fewer plants infected with AWR recorded in the test plot than in the control plot. In addition, the presence of the salad onion waste increased the growth of the overwintered crop (crop 1) by about 40%. The bulb onion waste analysed in the first year of the project was shown to contain nitrogen, phosphorus and potassium and this difference in size of the plants between the control and test plots suggests the composted waste had a fertiliser effect.

Field Trial at HRI-Kirton The presence of the composted onion waste had an effect on the viability of the sclerotia retrieved from the field site although there was no trend in effect. Similar to the commercial field trials, a number of the sclerotia viability assessments were made after the crop had been planted and hence the presence of these onions could have stimulated the sclerotia in the control plots to germinate. A high percentage of soft sclerotia was retrieved from the control plots after the onions had been planted. This, in conjunction with the lower recovery of sclerotia from plots with compost applied, may explain why no difference in viability between control and compost amended plots was detected.

The composted onion waste applied and incorporated at a 50% rate was not detrimental to onion emergence providing there was sufficient delay between application and planting, with emergence better in fresh compost than in stored. Control of AWR with the composted onion waste differed with onion variety and the condition of the compost. Fresh onion waste compost applied and incorporated at a 50% rate either 1 or 9 months prior to planting Rijnsburger sets was as effective as Folicur in controlling AWR throughout the growing season. Treatment with Folicur however was shown to be more effective than the compost treatments in controlling disease on Sturon variety sets. At harvest, the highest yield was obtained with the Folicur treated sets. A similar trend to emergence and control of AWR was observed with respect to yield, in that the fresh compost and Rijnsburger sets performed better than the stored compost and Sturon sets respectively.

Folicur (a.i. tebuconazole) is currently the only fungicide approved for the control of AWR in the UK. Other fungicides (eg: dichloran, iprodione, vinclozolin) have been used to control AWR in the past but are now no longer effective in controlling the disease due to problems such as enhanced microbial degradation by the soil microflora. Similar problems may arise with Folicur in the future and hence raises concern as to how long this product will be available to effectively control AWR.

A general observation of the field trial prior to harvest revealed evidence of phytotoxicity similar to that observed in the glasshouse. The plants in the compost

amended plots appeared smaller than those in the untreated control and Folicur treated plots. The results of the trial however suggest that the overall effect of this phytotoxicity on yield was quite small. The yields obtained from the compost amended and untreated control plots were similar and, with the exception of one of the compost treatments (treatment B, onion variety = Sturon), the largest percentage of healthy bulbs was in the 40-60 mm size category across treatments. To reduce the possibility of any phytotoxic effects of composted vegetable waste on onion growth, the length of time between applying the compost and sowing/planting the crop could be increased.

Conclusions

1. Onion wastes fall into two categories: wet (peelings, whole onions) with moisture content above 80% and dry (shale, tops) with moisture content below 32%.

2. Composting each category of waste alone is either impractical, in terms of the bulk of material involved, or produces large volumes of run-off and unpleasant odours. A wet: dry onion waste mixture prepared to an 80% moisture content is optimal in minimising run-off and odours produced during composting at 50 ºC for 7 days.

3. *Brassica* (broccoli, white cabbage and cauliflower) and carrot wastes have moisture contents of 90% or higher. Mixtures of *Brassica* and carrot waste with onion shale prepared to the same moisture content (80%) and conditions of incubation give similar results to the wet: dry onion waste mixture.

4. The composted onion, *Brassica* and carrot waste mixtures prepared were shown to contain nitrogen, phosphorus and potassium with measurable conductivities and thus have potential value as fertilisers. The composted onion waste had a very low pH and hence has potential as a suitable alternative to peat.

5. Temperatures of 48 ºC and above, held for 7 days in composting vegetable waste, destroys sclerotia of *Sclerotium cepivorum*.

6. Composting onion waste containing resting spores of *Olpidium brassicae* and chlamydospores of *Fusarium oxysporum* for 7 days at 50 ºC destroys all propagules of *O. brassicae* and reduces the viability of *F. oxysporum*.

7. Composting onion waste reduces the content of the white rot sclerotia germination stimulant, di-n-propyl disulphide (dpds) compared with fresh waste. Composting at a high temperature (54 ºC) however has no greater a detrimental effect on dpds content than composting at a lower temperature (42 ºC).

8. The effect of composted vegetable waste (onion, *Brassica* and carrot) in sandy loam and silt soils on the viability of sclerotia of *Sclerotium cepivorum* is dependent on the length of exposure and the amount of waste present. In general, the longer the sclerotia are in contact with the waste and the higher the rate of incorporation, the greater the reduction in viability.

9. The viability of sclerotia in peat soil is influenced by the presence of composted vegetable waste (onion, *Brassica* and carrot) although, unlike sandy loam and silt soils, there is no relationship with the duration of exposure on the reduction in viability.

10. In glasshouse pot tests, composted onion waste incorporated into soil at a 50% rate gives: good control of *Allium* white rot (AWR) in peat soil; variable disease control in sandy loam soil; and no disease control in silt soil. However, the field trial at HRI-Kirton demonstrated control of AWR using composted onion waste in sandy silt loam soil and thus confirms previous on-farm experiments in silt soil where control of AWR was observed.

11. No unpleasant odours and minimal run-off are produced during composting of vegetable waste (bulb onion, salad onion and sweetcorn + broccoli) mixtures, prepared to defined moisture contents, at 50 ºC for 7 days in bulk tunnels.

12. Composted onion waste applied and incorporated at a 50% rate reduces sclerotia viability under field conditions (sandy silt loam soil).

13. Composted onion waste applied and incorporated at a 50% rate is not detrimental to onion emergence providing there is sufficient delay between compost application and onion planting, with emergence better in fresh compost than in stored. Repeated application may enhance the disease control effect.

14. Control of AWR with composted onion waste differs with onion variety and condition (fresh or stored) of the compost. Fresh onion waste compost applied and incorporated at a 50% rate either 1 or 9 months prior to planting Rijnsburger sets is as effective as Folicur (a.i. tebuconazole) in controlling AWR throughout the growing season. Treatment with Folicur is more effective than compost treatments in controlling AWR on Sturon variety sets.

15. Composted onion waste is slightly phytotoxic to onion seed germination and growth although the overall effect on yield is minimal. Phytotoxicity of the waste may be reduced by having a sufficient delay between application and planting.

Technology Transfer

The project has provided a series of key results that will form the basis for commercial exploitation:

1. An environmentally acceptable controlled composting system for onion based waste which produces minimal odour and run off.

2. The compost produced is white rot free and has major reductions in other pathogens and pests.

3. The compost has the ability to reduce white rot disease when applied to white rot infested soil in the year prior to onion planting. The compost can be stored and repeated application may enhance the effect.

4. The compost has a significant fertiliser value and its low pH may render it suitable as a peat alternative.

5. Composting reduces the bulk of the waste and enables the compost to be applied to land rather than going to landfill saving haulage and landfill costs.

Exploitation

1. Goldwood (Moulton) Limited now use composted onion waste to control *Allium* white rot (AWR) in the field. A grower for Bedfordshire Growers Limited is utilising the knowledge gained from the project to compost onion waste with a view to returning land infected with AWR into production. G's Fresh Vegetables Limited are also considering building controlled composting units so that the onion and other vegetable waste is composted on site and only the compost is carted away for application to land, especially that infested with white rot.

2. Since the end of the project, large-scale (75 tonne) composting tests have been conducted by Goldwood (Moulton) Limited in conjunction with a commercial composting site. Goldwood (Moulton) Limited are now planning to construct purpose-built facilities for the composting of onion waste.

3. The procedure may not be considered financially viable for all consortium members at the moment but UK legislation for waste management is under scrutiny and, if like much of mainland Europe all green waste has to be composted rather than taken to landfill, this system could well become extremely important.

4. The procedure may be most appropriate immediately for organic onion producers where chemical use is prohibited or restricted. The compost would have both white rot control and fertiliser value. Discussions with the Henry Doubleday Research Association (HDRA) and Elm Farm have taken place to explore this opportunity. A joint HRI/Soil Association/Composting Association application for the DEFRA open competition on reviewing compost application in organic crop production is being made. In addition, the principles derived from this work

could also be utilised by growers composting directly on-farm where there is no risk of disseminating pathogens to other sites.

5. HDC will facilitate technology transfer through articles in HDC news (within 6 months of the project end) and the trade press (The Grower and Vegetable Farmer in association with HorTIPS), through the production of factsheets and guidelines (within 3 months of the project end) as required, and co-ordinating industry forums to discuss the potential of the procedure.

Future R & D resulting from the project

HRI is co-ordinating an EU funded project starting 1st March 2002 entitled "Recycling horticultural wastes to produce pathogen suppressant composts for sustainable vegetable crop production". Goldwood (Moulton) Limited will also be one of the project partners. The project will research methods to recycle problem plant-based wastes through controlled composting into pest and pathogen-free composts which have a consistent value in suppressing soil-borne pathogens in organic and low-input vegetable production. The work aims to determine the mechanism of disease suppression and to enhance the efficacy of composts. The work will examine the plant growth and nutrition effects of using composted plant-based wastes in sustainable vegetable production and propagation. Controlled composting methods will be devised in the laboratory and in large-scale systems. The work of 7 science groups (plant pathology and nutrition, compost science, metabolite chemistry, agronomy) and 7 industrial partners (producers of vegetables and biocontrol agents and composters) will be integrated. Pathogen/crop/waste compost interactions specific to Northern and Southern Europe will be examined.

Work originating in the HortLINK project will also be followed up as part of a DEFRA ROAME proposal "Integrated use of biological control agents for sustainable control of *Allium* white rot". Standardised, seedling bioassays will be used to assess the potential for combining composted onion waste with two biocontrol agent treatments for white rot control.

On-site testing of composted vegetable waste to control *Allium* white rot developed in this HortLINK project is continuing at Goldwood (Moulton) Limited and Bedfordshire Growers Limited. Since the end of the project, large-scale (75 tonne) composting tests have been conducted by Goldwood (Moulton) Limited in conjunction with a commercial composting site. Goldwood (Moulton) Limited are now planning to construct purpose-built facilities for the composting of onion waste.

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Appendix I

Komada selective medium for *Fusarium oxysporum*

Basal medium	
Dipotassium hydrogen phosphate K_2HPO_4	1.0 g
Potassium chloride KCl	0.5 g
Magnesium sulphate $MgSO_4$	0.5 g
Ethylenediaminetetra-acetic acid ferric-sodium salt	0.01 g
L-Asparagine	2.0 g
D-Galactose	20.0 g
Distilled water	960 ml

Adjust to pH 3.8 with *c*. 0.75 ml 10% v/v phosphoric acid. Then add:

Agar	15 g

Sterilise basal medium. When cool add 40 ml sterile water containing:

Pentachloronitrobenzene	0.75 g
Bile, bovine (ox gall)	0.5 g
Disodium tetraborate $Na_2B_4O_7.10H_2O$	1.0 g
Streptomycin sulphate	0.3 g

Adjust to pH 3.8 with *c*. 3.8 ml 10% v/v phosphoric acid.

Appendix II – Glasshouse Pot Bioassay Data

Onion Waste Pot Bioassay in Sandy Loam (Figures 2, 3 and 4)

SOFT SCLEROTIA

Treatment	Month			
	1	2	3	6
Control	10 ± 1.9	13 ± 2.1	17 ± 2.4	17 ± 2.3
1% Raw	8 ± 2.9	12 ± 3.4	14 ± 3.9	17 ± 4.1
10% Raw	5 ± 2.2	18 ± 4.4	23 ± 4.6	39 ± 5.6
50% Raw	8 ± 2.8	5 ± 2.4	21 ± 4.3	41 ± 6.1
1% 42 ºC compost	10 ± 2.3	12 ± 2.5	16 ± 2.8	18 ± 2.8
10% 42 ºC compost	5 ± 1.7	10 ± 2.3	21 ± 3.2	28 ± 4.0
50% 42 ºC compost	5 ± 1.6	10 ± 2.2	11 ± 2.3	39 ± 3.7
1% 54 ºC compost	8 ± 2.2	17 ± 2.9	20 ± 3.1	28 ± 3.3
10% 54 ºC compost	11 ± 2.3	15 ± 2.8	26 ± 3.7	41 ± 4.2
50% 54 ºC compost	18 ± 2.9	38 ± 4.1	26 ± 3.4	49 ± 3.8

Interaction	P value
month	<0.001
treat	<0.001
month.treat	0.003
treat.rate	<0.001
treat.waste	0.078
month.treat.rate	<0.001
month.treat.waste	0.406
treat.rate.waste	0.237
treat.waste.time	0.644
treat.waste.temp	<0.001
month.treat.rate.waste	0.038
month.treat.waste.time	0.655
treat.rate.waste.time	0.735
month.treat.waste.temp	0.295
treat.rate.waste.temp	0.003
treat.waste.time.temp	0.001
month.treat.rate.waste.time	0.898
month.treat.rate.waste.temp	0.030
month.treat.rate.waste.temp	0.304
treat.rate.waste.time.temp	0.950
month.treat.rate.waste.time.temp	0.946

GERMINATION

Treatment	
Control	92 ± 2.9
Raw	88 ± 3.4
3 d 42 ºC compost	78 ± 4.4
7 d 42 ºC compost	82 ± 4.0
3 d 54 ºC compost	73 ± 4.7
7 d 54 ºC compost	65 ± 5.4

Interaction	**P value**
month	0.056
treat	<0.001
month.treat	0.004
treat.rate	<0.001
treat.waste	<0.001
month.treat.rate	0.001
month.treat.waste	0.147
treat.rate.waste	<0.001
treat.waste.time	0.889
treat.waste.temp	<0.001
month.treat.rate.waste	0.883
month.treat.waste.time	0.295
treat.rate.waste.time	0.720
month.treat.waste.temp	0.617
treat.rate.waste.temp	0.277
treat.waste.time.temp	0.039
month.treat.rate.waste.time	0.188
month.treat.rate.waste.temp	0.323
month.treat.waste.time.temp	0.168
treat.rate.waste.time.temp	0.292
month.treat.rate.waste.time.temp	0.955

Treatment Codes for the following bioassays
CAB =White Cabbage
BF = Broccoli Florets
CRT = Whole Carrots
OP = Onion Peelings
WCW = Wet Carrot Waste
BS = Broccoli Stalks
BS + CF = Broccoli + Cauliflower Waste

***Brassica* Waste, Carrot Waste + Onion Shale Pot Bioassay in Sandy Loam**
(Figures 5, 6, 7 and 8)

SOFT SCLEROTIA

Treatment	**Rate**		
	1%	**10%**	**50%**
Control	4 ± 0.5		
Raw CAB	10 ± 2.2	8 ± 1.9	7 ± 1.7
Compost CAB	8 ± 1.8	9 ± 1.9	25 ± 3.1
Raw BF	7 ± 1.6	13 ± 2.2	9 ± 1.9
Compost BF	6 ± 1.5	5 ± 1.5	12 ± 2.2
Raw CRT	7 ± 1.8	10 ± 2.0	7 ± 1.7
Compost CRT	5 ± 1.4	19 ± 2.7	20 ± 2.7
Raw WCW	5 ± 1.4	10 ± 2.2	16 ± 2.6
Compost WCW	8 ± 1.9	11 ± 2.3	19 ± 2.6
Raw BS	8 ± 1.9	14 ± 2.3	11 ± 2.3
Compost BS	8 ± 1.8	14 ± 2.3	12 ± 2.1
Raw BS + CF	5 ± 1.5	10 ± 2.0	13 ± 2.4
Compost BS + CF	13 ± 2.1	6 ± 1.6	8 ± 1.8

Interaction	**P value**
month	<0.001
treat	<0.001
month.treat	0.097
treat.rate	<0.001
treat.waste	<0.001
treat.source	0.008
month.treat.rate	0.022
month.treat.waste	0.034
treat.rate.waste	<0.001
month.treat.source	0.598
treat.rate.source	<0.001
treat.waste.source	<0.001
month.treat.rate.waste	0.180
month.treat.rate.source	0.170
month.treat.waste.source	0.496
treat.rate.waste.source	<0.001
month.treat.rate.waste.source	0.545

GERMINATION

Treatment	Raw	Composted
Control	98 ± 0.8	
CAB	98 ± 1.3	89 ± 2.6
BF	93 ± 2.1	82 ± 3.2
CRT	97 ± 1.3	79 ± 3.3
WCW	91 ± 2.5	84 ± 3.1
BS	94 ± 1.9	91 ± 2.3
BS + CF	95 ± 1.7	83 ± 3.0

Interaction	P value
month	<0.001
treat	<0.001
month.treat	0.130
treat.rate	<0.001
treat.waste	<0.001
treat.source	<0.001
month.treat.rate	0.015
month.treat.waste	0.108
treat.rate.waste	<0.001
month.treat.source	0.005
treat.rate.source	<0.001
treat.waste.source	0.001
month.treat.rate.waste	0.156
month.treat.rate.source	0.908
month.treat.waste.source	0.887
treat.rate.waste.source	0.143
month.treat.rate.waste.source	0.976

Onion and Other Vegetable Waste Pot Bioassay in Sandy Loam (9 and 12 months) (Figures 9 and 10)

SOFT SCLEROTIA

Treatment	Rate		
	1%	10%	50%
Control	17 ± 1.8		
CAB	18 ± 2.6	23 ± 2.9	40 ± 3.4
BF	23 ± 2.8	31 ± 3.2	45 ± 3.5
CRT	22 ± 2.9	27 ± 3.2	36 ± 3.8
OP	29 ± 3.4	53 ± 3.9	53 ± 4.5

Interaction	P value
month	0.207
treat	<0.001
month.treat	0.757
treat.rate	<0.001
treat.waste	0.557
treat.source	<0.001
month.treat.rate	0.954
month.treat.waste	0.161
treat.rate.waste	0.034
month.treat.source	0.265
treat.rate.source	0.168
treat.waste.source	0.204
month.treat.rate.waste	0.896
month.treat.rate.source	0.300
month.treat.rate.source	0.797
treat.rate.waste.source	0.317
month.treat.rate.waste.source	0.751

GERMINATION

Treatment	9 months	12 months
Control	99 ± 1.9	98 ± 2.8
Raw CAB	98 ± 2.7	100 ± 0.1
Compost CAB	85 ± 7.9	84 ± 7.9
Raw BF	73 ± 9.9	92 ± 6.4
Compost BF	81 ± 8.8	66 ± 10.1
Raw CRT	97 ± 3.5	98 ± 3.2
Compost CRT	81 ± 9.7	76 ± 9.0
Raw OP	81 ± 10.4	91 ± 7.6
Compost OP	77 ± 10.7	92 ± 8.5

Interaction	P value
month	0.482
treat	<0.001
month.treat	0.414
treat.rate	<0.001
treat.waste	<0.001
treat.source	<0.001
month.treat.rate	0.783
month.treat.waste	0.003
treat.rate.waste	0.122
month.treat.source	0.504
treat.rate.source	0.015
treat.waste.source	<0.001
month.treat.rate.waste	0.074
month.treat.rate.source	0.162
month.treat.waste.source	0.018
treat.rate.waste.source	0.237
month.treat.rate.waste.source	1.000

Onion and Other Vegetable Waste Pot Bioassay in Silt (Figures 11, 12, 13 and 14)

SOFT SCLEROTIA

Treatment	Month					
	1	2	3	6	9	12
Control	11 ± 1.3	10 ± 1.3	13 ± 1.4	13 ± 1.5	15 ± 1.5	18 ± 1.6
1% Raw CAB	13 ± 3.4	15 ± 3.5	11 ± 3.1	17 ± 4.2	14 ± 3.5	19 ± 3.9
10% Raw CAB	31 ± 4.6	27 ± 4.6	27 ± 5.0	32 ± 5.4	30 ± 4.5	76 ± 5.7
50% Raw CAB	27 ± 4.4	33 ± 5.1	36 ± 6.9	21 ± 9.3	36 ± 5.2	88 ± 4.4
1% Compost CAB	6 ± 2.4	6 ± 2.4	3 ± 1.8	9 ± 2.8	9 ± 3.0	12 ± 3.3
10% Compost CAB	6 ± 2.5	13 ± 3.3	12 ± 3.2	9 ± 3.2	19 ± 4.8	14 ± 3.5
50% Compost CAB	10 ± 3.7	15 ± 3.6	14 ± 3.7	28 ± 5.0	27 ± 4.8	76 ± 4.7
1% Raw BF	12 ± 3.2	13 ± 3.4	10 ± 3.1	19 ± 4.5	17 ± 3.8	18 ± 4.1
10% Raw BF	19 ± 4.0	15 ± 3.7	19 ± 5.2	17 ± 4.3	32 ± 5.2	49 ± 6.6
50% Raw BF	10 ± 3.7	15 ± 4.3	10 ± 3.1	31 ± 6.2	23 ± 5.4	87 ± 3.8
1% Compost BF	8 ± 3.2	6 ± 2.4	6 ± 2.4	6 ± 2.4	6 ± 2.6	15 ± 3.7
10% Compost BF	9 ± 2.8	12 ± 3.3	13 ± 3.4	11 ± 3.3	13 ± 3.2	21 ± 4.1
50% Compost BF	16 ± 3.6	18 ± 3.8	16 ± 3.6	32 ± 5.4	30 ± 4.9	76 ± 4.9
1% Raw CRT	15 ± 3.6	12 ± 3.3	7 ± 2.6	11 ± 3.1	9 ± 3.0	17 ± 4.2
10% Raw CRT	22 ± 4.2	27 ± 4.6	19 ± 4.2	15 ± 3.5	26 ± 5.5	26 ± 4.8
50% Raw CRT	12 ± 3.3	13 ± 4.2	13 ± 4.1	33 ± 6.0	31 ± 6.6	89 ± 3.3
1% Compost CRT	5 ± 2.1	8 ± 2.7	6 ± 2.4	4 ± 1.9	8 ± 2.7	10 ± 3.0
10% Compost CRT	15 ± 3.6	8 ± 2.8	14 ± 3.6	12 ± 3.6	21 ± 4.0	18 ± 4.0
50% Compost CRT	5 ± 2.1	17 ± 3.8	19 ± 4.0	23 ± 5.8	23 ± 4.7	39 ± 5.1
1% Raw OP	11 ± 3.2	13 ± 3.4	10 ± 3.0	12 ± 3.7	13 ± 3.3	14 ± 3.5
10% Raw OP	23 ± 5.2	27 ± 4.6	22 ± 4.5	26 ± 6.2	29 ± 5.0	83 ± 5.0
50% Raw OP	27 ± 5.3	29 ± 4.6	25 ± 6.1	48 ± 6.2	39 ± 5.9	94 ± 2.8
1% Compost OP	6 ± 2.3	13 ± 3.4	5 ± 2.3	8 ± 2.8	11 ± 3.1	11 ± 3.3
10% Compost OP	30 ± 4.6	27 ± 5.5	30 ± 5.7	35 ± 8.2	44 ± 5.2	81 ± 5.2
50% Compost OP	17 ± 3.7	22 ± 4.4	14 ± 3.7	28 ± 5.7	25 ± 5.0	78 ± 7.3

Interaction	P value
month	<0.001
treat	<0.001
month.treat	<0.001
treat.rate	<0.001
treat.waste	<0.001
treat.source	<0.001
month.treat.rate	<0.001
month.treat.waste	<0.001
treat.rate.waste	0.869
month.treat.source	0.002
treat.rate.source	<0.001
treat.waste.source	<0.001
month.treat.rate.waste	0.039
month.treat.rate.source	0.032
month.treat.waste.source	0.477
treat.rate.waste.source	<0.001
month.treat.rate.waste.source	0.044

GERMINATION

Treatment	
Control	92 ± 1.2
Raw CAB	81 ± 2.7
Compost CAB	92 ± 1.8
Raw BF	77 ± 2.9
Compost BF	85 ± 2.3
Raw CRT	85 ± 2.4
Compost CRT	86 ± 2.2
Raw OP	87 ± 2.4
Compost OP	82 ± 2.7

Interaction	**P value**
month	<0.001
treat	<0.001
month.treat	<0.001
treat.rate	<0.001
treat.waste	<0.001
treat.source	0.006
month.treat.rate	<0.001
month.treat.waste	0.131
treat.rate.waste	0.007
month.treat.source	0.544
treat.rate.source	<0.001
treat.waste.source	<0.001
month.treat.rate.waste	0.971
month.treat.rate.source	0.771
month.treat.waste.source	0.123
treat.rate.waste.source	0.512
month.treat.rate.waste.source	0.190

Onion and Other Vegetable Waste Pot Bioassay in Peat (Figures 15, 16 and 17)

SOFT SCLEROTIA

Treatment	
Control	6 ± 0.8
1% CAB	5 ± 1.1
10% CAB	7 ± 1.3
50% CAB	11 ± 1.7
1% BF	7 ± 1.2
10% BF	9 ± 1.4
50% BF	9 ± 1.5
1% CRT	4 ± 0.9
10% CRT	5 ± 1.1
50% CRT	7 ± 1.3
1% OP	9 ± 1.4
10% OP	15 ± 2.0
50% OP	24 ± 2.8

Interaction	**P value**
month	<0.001
treat	<0.001
month.treat	0.823
treat.rate	<0.001
treat.waste	0.121
treat.source	<0.001
month.treat.rate	0.446
month.treat.waste	0.521
treat.rate.waste	0.837
month.treat.source	0.074
treat.rate.source	0.002
treat.waste.source	0.101
month.treat.rate.waste	0.442
month.treat.rate.source	0.937
month.treat.waste.source	0.143
treat.rate.waste.source	0.165
month.treat.rate.waste.source	0.814

GERMINATION

Treatment	Rate		
	1%	10%	50%
Control	94 ± 0.9		
Raw CAB	93 ± 1.9	95 ± 1.8	89 ± 2.7
Compost CAB	93 ± 1.9	96 ± 1.6	90 ± 2.3
Raw BF	92 ± 2.1	90 ± 2.4	61 ± 4.0
Compost BF	93 ± 1.9	91 ± 2.2	80 ± 3.3
Raw CRT	93 ± 1.9	92 ± 2.2	90 ± 2.3
Compost CRT	96 ± 1.4	93 ± 1.9	79 ± 3.1
Raw OP	94 ± 1.8	91 ± 2.4	77 ± 4.8
Compost OP	93 ± 2.1	81 ± 3.9	73 ± 5.2

Interaction	P value
month	0.001
treat	<0.001
month.treat	0.978
treat.rate	<0.001
treat.waste	0.502
treat.source	<0.001
month.treat.rate	<0.001
month.treat.waste	0.583
treat.rate.waste	0.609
month.treat.source	0.114
treat.rate.source	0.033
treat.waste.source	<0.001
month.treat.rate.waste	0.406
month.treat.rate.source	0.236
month.treat.waste.source	0.139
treat.rate.waste.source	0.030
month.treat.rate.waste.source	0.131

Appendix III

Industry Guidelines for Composting and Utilisation of Onion and Other Vegetable Wastes (Milestone 6.6)

Composting of Vegetable Waste

Uncontrolled composting in static or turned windrows can result in a significant reduction in the volume of waste but, due to the variable temperatures throughout the heap, does not ensure all pests and pathogens are destroyed, thus limiting the ease of disposal of the processed compost. In addition, uncontrolled composting can result in the production of unpleasant odours and run-off pollution. This problem can be overcome with the use of aerated bulk composting tunnels. Waste for composting is housed on a slatted floor above a plenum through which a controlled flow of air is blown. This maintains a uniform temperature throughout the waste and ensures that all pathogens and pests with a thermal death point below the waste temperature are destroyed.

Two types of aerated bulk composting tunnel have been designed at Horticulture Research International, Wellesbourne:

Type 1 consists of a modified insulated cargo container with internal dimensions of 11.8 x 2.2 x 2.4 (high) m (volume 62.3 m^3) (Figure 1). A slatted steel bar floor with 40% air space is mounted 0.23 m above the base of the tunnel which can be filled with *c.* 20 tonnes of waste to a height of 1.5 m through double doors situated at one end.

Type 2 consists of an insulated polythene tunnel inside which are two 2.4 m high parallel walls, joined by a wall at one end (Figure 1). The compost can be filled between the walls on to a 3 x 2.05 m slatted bar floor with 75% air space mounted 0.5 m above the base of the tunnel. The compost is enclosed by a removable end wall, which fits across the sidewalls. This design has a capacity of 14.8 m^3 and can be filled with *c.* 6 tonnes of waste to a height of 1.5 m. A "Bobcat" front-end loader is used to fill and empty the tunnels.

Figure1: Type 1 (left) and Type 2 (right) controlled composting bulk tunnels

The ventilation system, mounted at the closed end of the tunnels provides a controlled flow of air into the plenum and through the compost before being either recirculated through the plenum or discharged through a vent at the far end of the tunnels. A motorised damper regulates the proportion of cooler fresh air to warmer recirculated air passing into the plenum. Platinum resistance temperature sensors are mounted in the air space above and below the compost, and in four positions in the compost at a depth of 0.5 m. If the compost temperature exceeds 60 ºC, the fresh air damper is gradually opened and the airflow increased.

Vegetable Wastes Suitable for Composting

There are two categories of vegetable wastes:

1. Wet - moisture contents above 80% (eg: onion peelings, crushed whole bulbs, white cabbage, broccoli stalks and florets, cauliflower leaves, chopped whole carrots, wet carrot waste)

2. Dry - moisture contents below 30% (eg: onion shale)

Composting each category of waste alone is either impractical, in terms of the bulk of material involved, or produces large volumes of run-off and unpleasant odours.

- Vegetable waste mixtures with a moisture content of 80% are optimal to minimise run-off produced during composting
- Onion shale and straw are suitable materials to mix with wet wastes to reduce their moisture content
- A 10:1 ratio of wet: dry wastes will produce a waste mixture with a moisture content of *c.* 80%
- The waste requires aeration (either frequent turning in a windrow system or a ventilation system in a bulk tunnel) to avoid unpleasant odours during composting

For vegetable waste to be safely returned to the field after composting without contaminating the land, it must be pathogen and pest free.

- Waste composted for 7 days at 50 ºC under controlled conditions will ensure pathogens such as *Sclerotium cepivorum* and *Olpidium brassicae*, and pests such as onion fly larvae and nematodes are destroyed

Utilisation of Composted Vegetable Wastes

Composted onion waste applied and incorporated to land at a 50% rate:

- Reduces viability of sclerotia of *S. cepivorum*
- Is not detrimental to onion emergence providing there is sufficient delay between compost application and onion planting
- Is as effective as Folicur in controlling *Allium* white rot throughout the growing season. Freshly made compost performs better than stored.

To avoid any potential phytotoxicity of waste applied to land:

- Onion crops should not be planted on land in the same year of compost application

In addition to white rot control, composted onion, *Brassica* and carrot waste mixed with onion shale contain nitrogen, phosphorus and potassium and thus have potential value as fertilisers.

Benefits to Industry

- Return of onion growing land currently infested with white rot to onion production
- Less reliance on chemical treatments and reduction in length of crop rotations currently needed to avoid build-up of the white rot pathogen
- Reduction in transportation and landfill costs