FINAL REPORT

Date:26Sep00

CRDC Project Number: **NEC5C**

Hygiene, fertilizer equivalence, soil pathogen suppression, and guidelines for production of cotton gin trash compost.

CRDC Program No. **7.2**

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Published in September 2000 by the National Centre for Engineering Agriculture, Toowoomba. Material from this publication may not be used unless prior written approval has been obtained from the National Centre for Engineering in Agriculture and the Cotton Research and Development Corporation. Publication No. 179744/1

Acknowledgements

This project was funded by the Cotton Research and Development Corporation. The contribution of many people in the cotton industry is also gratefully acknowledged.

Summary

This project came about following a suggestion from the Australian Cotton Ginners Association.

The cotton ginning sector currently produces around 143,500 tonnes of trash per year, and current methods of use / disposal are marginally adequate. It is expected that in the near future, new methods of use / disposal will be required.

Composting is a process of oxidising organic materials to produce heat, gases, and more stable organic materials termed humus, which have a vital role in soil health. Composting represents a controlled form of what goes on in stockpiles at present, and is a leading candidate method of using / disposing of gin trash.

Before composting can be widely adopted, questions must first be answered about what is in the organic material prior to composting, what is left after composting, and whether it can be done at reasonable cost keeping in mind its low mass and low value per unit volume.

Gin trash and mixtures of gin trash were composted using a minimum of equipment and labour inputs. Questions of cotton pathogens and synthetic chemical residues were addressed by lab testing pre- and post- composting. Guidelines were developed for overcoming practical problems. Wetting the trash initially was a problem until water was applied at low rates often, timed to operate during the early hours of the morning to minimize drift and evaporation. The trash was handled so that all of it spent enough time in the hot zone within the windrow for the heat to remove pathogens and chemical residues. Work was done to develop better methods of determining the time to end composting so that immature compost does not compete with young plants for nitrogen. Guidelines are included on how to use the compost for best agronomic results.

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2. Background

This project came about following a suggestion from Ron Jett and other members of the Australian Cotton Ginners Association.

The ginning sector in Australia currently processes around 3,000,000 bales of cotton lint per year. At an estimated 8% trash in seedcotton, and a typical 38% turnout, this represents approximately 143,500 tonnes of trash per year.

Current methods of use/disposal of this material are marginally adequate. It is expected that in the next few years the industry will expand further, and also that environmental controls over some of the current methods will become tighter. This indicates a need to find new ways to dispose of and use this by-product.

2.1 Composting

Composting is accepted as a low technology bio-oxidative process that reduces the volume of organic waste by up to 50% (de Bertoldi *et al.* 1985). Biologically active organic fractions are converted into humus and microbial biomass, suitable for agricultural use as a slow-release fertiliser and soil conditioner. The carbon to nitrogen ratio of cotton trash is 30, which is within the acceptable range for composting to proceed. Hence bio-oxidation will occur naturally within stockpiles of cotton trash. However uncontrolled composting may produce foul odours and nutrient-rich leachates polluting the environment, and may result in spontaneous combustion. If volume reduction is to be maximised, under conditions that favour the destruction of pathogens and weed seeds, then the development of appropriate process controls is essential.

Cellulose, the major constituent of plant cell walls, is the most abundant form of organic carbon on the earth. With the exception of 15% of lignin, most of the plant-derived material in cotton trash is microbially-available cellulose. Gin trash is comprised of 20% leaf material, 35% sticks, stems and hulls, and 40% lint (Thomasson and Willcutt 1996). However a high proportion of the leaf and lint material includes waxes, deposited in the plant cuticle. The presence of these waxes renders the trash hydrophobic. The predominant cellulose decomposers are bacterial and fungal in origin, requiring high water contents for activity. Provided water is adequate, cellulose degradation can occur both aerobically and anaerobically. Aerobic (oxidative) processes occur much more rapidly, with carbon dioxide the main gaseous byproduct. Under anaerobic conditions hydrogen sulphide and methane gas may be produced, resulting in obnoxious odours and increasing the risk of spontaneous combustion (Hogland *et al.* 1996).

The main factor controlling aeration is the bulk density of the organic feedstock. Cotton trash has a relatively low bulk density (112 kg/m3), and due to the presence of a high proportion of cuticular waxes, can be difficult to wet up (Thomasson and Willcutt 1996). Accordingly, the rate of bio-oxidation of cotton trash under uncontrolled, outdoor storage conditions can be very slow (3 years under Australian conditions). Increasing the bulk density will increase the water holding capacity of the feedstock, but will also reduce the convective heat loss (Hogland *et al.* 1996). As a consequence, within compost windrows the metabolic heat produced by microbes may increase

internal temperatures up to 90°C. The optimal temperature range for most microbes - including plant pathogens, is 25-40°C (Madigan *et al.* 1997). However the majority of the soil-dwelling, antibiotic-producing actinomycete bacteria can grow within the range of 45-60°C. Much above 65°C, many microbes are killed, with the exception of a few extreme bacterial thermophiles (Hellmann *et al.* 1997). Therefore maintaining the internal temperature of a windrow between 45 and 65°C will limit the activity of plant pathogenic microbes, but will favour the activity of the beneficial actinomycetes. Temperatures within this range are also known to destroy most weed seeds (Powles *et al.* 1988). Temperatures above 65°C will reduce the activity and survival of the actinomycetes and other potentially antagonistic bacteria, rendering the finished compost prone to reinfestation by plant pathogens.

2.2 HACCP and cotton trash composting

The methodology of Hazard Analysis and Critical Control Points (HACCP) is commonly used in the food industry to improve the quality and safety of products. Potential hazards are identified in the raw constituents and along the production line (Hazard Analysis). Process factors or sourcing protocols most likely to minimise or to exclude a specified hazard, are then nominated as Critical Control Points (hence HACCP). The critical control points identified then become the basis of monitoring protocols, to ensure process control. The aim of this project was to identify the hazards most likely to jeopardise the reuse of composted cotton trash as an organic fertiliser, and to identify cost-effective critical control points for process control.

The hazards most likely to be in the cotton trash are pesticide residues, weed seeds and plant pathogens. Of the chemical residues, organochlorine pesticides are the most likely to persist. Thermophillic composting is accepted as one of the best methods to biologically degrade organic aromatic chemicals (Crawford *et al.* 1993). However the persistence and concentration of pesticide used will vary between cotton-growing regions. For this reason, a preliminary survey was done on late-season samples of trash from gins around north-eastern Australia, to indicate the likely levels of pesticide residues in cotton trash.

A recent outbreak of fusarium wilt of cotton in Southeast Queensland has accentuated the need for effective local hygiene and quarantine. Although most fungal plant pathogens are inactivated by heat above 55°C, some strains of the fusarium wilt fungus can tolerate higher temperatures (Bollen and Volker 1996). Therefore to minimise the likelihood of reinfestation of the mature compost with plant pathogens, populations of the heat-resilient, antagonistic actinomycete bacteria have to be encouraged. To do this, maintaining the water content to favour bacterial activity and managing the bulk density to maintain internal windrow temperatures between 45 and 65°C, were nominated as critical control points for this project.

2.3 Compost application to soil and soil health

Organic carbon is the corner-stone of primary production. The content and diversity of organic matter in the soil is fundamental to the dynamics of nutrient recycling (Follett 1987). However with the intensification of cropping systems and the dependence on inorganic fertilisers, the

organic carbon content of both broadacre and intensive cropping lands has dropped substantially (Dalal and Mayer 1986). The reduction and limited diversity of organic inputs has contributed to a decline in soil structure and an increase in soilborne diseases (Kennedy and Smith 1995). Composting organic wastes prior to land application has the potential to add biologically active organic carbon to soil, whilst maintaining local farm hygiene and quarantine. Moreover the microbiological stability of mature composts reduces the potential for mineralisation of pre-existing organic carbon in the soil, and nutrient draw-down (Pascual *et al.* 1999). High rates of compost addition to soil can also aid in the management of soilborne diseases (Hoitink *et al.* 1991). Hence two of the objectives for this project were to develop indices for compost maturity, and to investigate the potential for high rates of compost application to assist in controlling soilborne diseases of cotton using fusarium wilt as the model system.

Composts vary substantially in their degree of maturity, and few guidelines exist on what rates should be applied to cropping soils (Bernal et al 1998). Composts are accepted as slow-release forms of the major elements N, P and K (Marchesini et al 1988), but few research papers discriminate between total and available nutrient concentrations. To reduce the potential for excessive nutrient build-up in cropping soil over time, scientists are advocating that rates of application should be based on their inorganic N and P concentrations (Gagnon and Simard 1999). Yet to date the only method for determining the rate of mineralisation of a compost over time is soil testing. If a laboratory-based test could be developed to indicate likely mineralisation rates, then farmers could budget the fertiliser contributions from composts for both the immediate and subsequent crops.

Ion exchange resins have been used successfully to investigate changes in the availability of nutrients in mushroom composts (Beyer 1998). Therefore another objective of this project was to investigate the potential of ion exchange resins to predict the mineralisation rate of composts. On the basis of the available N, P and K content of the mature compost, the fertiliser equivalence of the compost at the time of application could be determined using conventional laboratory testing, with the ion exchange resin test predicting mineralisation in the short-term. Substituting inorganic fertiliser inputs with a mature compost would then become more feasible, with the added benefit of improving soil health. However to expedite the local reuse of the composted cotton trash on-farm, the capital outlay, complexity and labour requirements have to be low. Accordingly passively aerated windrows with a low turning frequency, using locally available earth-moving equipment was selected for this trial.

Composting gin trash is common overseas and there are several *ad hoc* trial sites in Australia.

This project includes work on mixing cotton trash with other wastes such as animal manures and wood sawdust. This is because such mixtures offer important benefits by way of:

- Increasing particle size so that the windrows remain properly aerated;
- Improving the water retention of the trash mixture;
- Increasing the value of the resulting fertilizer in terms of its chemical makeup;
- Increasing the rate of biological activity and hence heat generation within the windrows to maximize pathogen propagule and weed seed destruction;
- Decreasing the chance of nutrient leaching or volatilisation by locking those fractions up in the microbial biomass;

2.4 Why compost?

Composting can convert gin trash from a dusty, low density and difficult to transport waste into a stable, readily transported by-product.

Cotton pathogens, most weed seeds and synthetic chemicals are removed when the material spends sufficient time in the hot zone of a composting windrow.

Current means of use or disposal of trash are marginal and are expected to have limited futures. Trash dumped in large heaps will naturally compost, but in an uncontrolled manner. Under certain conditions of temperature and oxygen supply, the material may spontaneously combust, causing smoke hazard and a fire that is notoriously difficult to extinguish.

Stockpiling has worked in the past, but at some point a proper long term destination for the material will need to be found. Anxiety about chemical residues and soil diseases has meant that in most areas there are no other means of disposal that could cope.

Compost is a useful source of soil organic carbon to replace that lost through intensive cultivation. The humus that is produced is longer lasting than organic carbon arising from (for example) uncomposted animal manure. This humus encourages more varied soil micro-organism populations, usually at the expense of cotton pathogens, and improves soil health.

The compost also has chemical properties that improve soil physical structure.

Gins report annual handling costs of between zero and $60,000 per year. This can be replaced by the unrealized value of the fertilizer equivalent of the 143,500 tonnes of trash mentioned above, once properly composted.

2.5 Why not compost?

On a percentage dry-weight basis, the N, P, and K content of cotton trash is of the order of 1.3, 0.45 and 0.36% respectively (Miller and Jones 1995). Hence some cotton growers have applied trash to their soil, as an organic fertiliser. However, trash from the joint pool of a gin receiving cotton from hundreds of kilometres around can reasonably be expected to contain propagules of whatever diseases are present in the grower catchment of that gin, including *Fusarium oxysporum* f.sp. *vas infectum* ('FoV') and *Verticillium*. It can also be expected to contain residues of certain persistent synthetic pesticides.

The thermal effects of composting have been shown to remove these unwanted components. However, the thermal effects do not occur at the surface of a windrow and along the edges. At these places, it is likely that sufficient unwanted components will persist to cause problems. Commercially available machinery for turning compost in windrows is not specifically designed to bring the edges into the hot core, because the machinery is primarily designed to macerate and aerate, but not necessarily circulate. That all material will spend time in the core is not guaranteed. It is therefore necesssary to take steps to ensure that it is.

Compost applied to soil before the composting process is complete can cause a phenomenon called nutrient drawdown. This is where, instead of adding nutrients to the soil, the micro-

organisms in the compost take nutrients from the soil to better continue with the composting process.

Once the compost is mature and temperatures drop, it can become re-infested with saphrophyllic microorganisms such as those responsible for seedling diseases.

Finally, composting represents a distraction from usual ginning practice that requires finance and management time.

3. Objectives

Conduct a survey of gin trash at a representative sample of gins (eight sites in NSW and Qld) throughout the ginning season;
Completed (9 sites). Most gins had finished for the season by the time this project was approved to commence, so only one late season sample could be taken from each.
Test output of sites where gin trash is currently being composted on a commercial or trial basis;
Completed (3 sites).
Set up a medium scale site at a cooperating gin in Cecil Plains or Dalby:

- **Monitor requirements for turning and watering according to internal temperature requirements;**
- **Compare composting with and without the addition of animal manures and sawdust;**
- **Measure organo-chlorine, and organo-phosphate levels (pre- and post-composting), and NPK levels (post-composting).**

Completed.
Set up pot trials to measure the suppression of Verticillium and Fusarium using suitable output from the composting site.
Begun. Due to emergence problems during winter in Toowoomba in a glass house not previously used for this kind of work, these trials will be completed and reported after this report is submitted. There will be no further costs to the CRDC for this.
Reports: Test Results and Guidelines.
Completed.

4. Materials and Methods

4.1 Overview of Method

Initially a survey was taken of gin trash from a selection of gins in Queensland and NSW, to answer questions about what exactly is in gin trash, in terms of its chemical makeup and whether certain pesticides or certain cotton pathogens were present.

The main part of the project was concerned with setting up a site in Dalby where gin trash was

composted and the end product was analysed.

There were two main emphases in this. Firstly, extensive laboratory analysis was carried out on the composting material before, during and after the compost process. Secondly, the handling of the composting material was done in a 'low tech and low input' manner so that if the work was to be replicated later by others then there were no special requirements for machinery, instrumentation, or labour over and above that available to the typical gin manager.

Cotton trash from a gin on the Darling Downs was laid in windrows in three lots: by itself, mixed with feedlot manure, and mixed with feedlot manure and cypress pine sawdust. No special equipment was used to form the windrows or to turn them subsequently. Samples were taken to measure the chemical make-up of the trash and also to determine what (if any) herbicides and pesticides were present. The three windrows were watered thoroughly and kept moist for a period of five months while monitoring the internal temperatures.

Early in the process, mesh bags containing cotton plant material known to be infected with *Fusarium oxysporum* f.sp. *vas infectum* (FoV) were buried within the windrows for a two week period. Similar bags were kept out of the windrows. The bags were then sent for laboratory analysis.

At approximately five week intervals the material was turned, using a conventional backhoe/loader. Care was taken to ensure that all of the material spent a period in the hot core of the windrows. The composting materials were analysed to determine their physical characteristics and also the changing chemical make-up.

The practical problems of composting in this way while keeping time and cost at a minimum were assessed.

At the end of this process, when all of the material in the windrows had been changed into stable and mature compost, material was again checked for chemical make-up and the presence of herbicides and pesticides.

The chemical make-up of the material in the windrows before, during and after composting was analysed to provide information on the relative value of the compost, the proper time to stop the process, and the best way to apply it on broadacre farming.

After the composting had taken place, mature compost from each windrow was mixed with soil from a field known to be heavily infected with FoV, and with an inert material. The nutrient status of the soils was made constant across the trial to remove that variable. An FoV susceptible cotton variety was then grown, and its health was monitored by reference to circulating carbohydrates to determine whether the compost-added soils had a positive effect on plant health.

4.2 Survey of gin trash

4.2.1 Pesticide residues

Trash samples were obtained from nine gins in Queensland and New South Wales. The gins were coded as follows:

Site	Description
T1	Gin stockpile, Macintyre Valley
T2	Gin stockpile, western NSW
T3	Gin stockpile, Macquarie Valley
T4	Gin stockpile, Macquarie Valley
T5	Gin stockpile, Emerald
T6	Gin stockpile, St George-Dirranbandi
T7	Gin stockpile, Gwydir Valley
T8	Gin stockpile, western NSW
T9	Gin stockpile, eastern Darling Downs

In addition, the end product of three *ad hoc* gin trash composting sites in Queensland and New South Wales was sampled. The sites were coded as follows:

Site	Description
C1	Composting site Macintyre Valley
C2	Composting site StGeorge-Dirranbandi
C3	Composting site lower Namoi Valley

By the date that the project formally started, many gins had finished ginning for the season. In each case the samples were taken by local staff, who were requested to take from 10 points in the most recent part of their stockpiles, at a depth of 150mm, to fill each of two '3kg Postpak' satchels with a total of 1kg of trash (or end product). Trash from 'yard cotton' was to be excluded.

The satchels were then posted directly to laboratories for chemical analysis and pathogen screening.

Chemical analyses of the trash samples were carried out for organochlorine (HCB, gamma BHC-Lindane, Heptachlor, Aldrin, BHC, Heptachlor epoxide, Chlordane *trans* and *cis*, DDE, Dieldrin, Endrin, DDD, DDT, Methoxychlor, and total Endosulfan), PCB, and organophosphate (Demeton-S-methyl, Diazinon, Dimethoate, Pirimiphos-methyl, Chlorpyrophos, Parathion, Malathion, Fenthion, Ethion, and Azinphos-methyl). The AGAL Pty Ltd laboratory was used.

4.2.2 Cotton Pathogens

The trash was analyzed by the Queensland Department of Primary Industry laboratory in Indooroopilly, Brisbane for cotton pathogens. Two methods were used. Firstly, fragments of the trash were examined directly ('direct plating') for signs of pathogens. Secondly, bioassays were set up. The trash or compost was mixed 50/50 (vol/vol) with potting mix and placed into a seedling tray. Twenty-five seeds of a cotton variety known to be susceptable to FoV (Siokra 1-4) were planted in each tray. The second method is capable of showing up pathogens where the former fails, but takes longer to complete.

4.3 Feedstock mix and management of windrows

Cotton trash from the Dalby Queensland Cotton Gin, processed toward the end of the 1999 harvesting season was used for the trial. Manure recently cleared from the Sandalwood Feedlot (Quinalow Qld.), and native cypress sawdust transported from the Kogan Timber Mill were used to vary the bulk density and chemical composition of the composts. Three windrows were constructed on a compacted earthen pad adjacent to the trash stockpiles at the Dalby gin site, on 5/8/'99.

In keeping with the low cost, low management time, and low tech emphasis in the composting operations, the windrows were formed by the dumping action of a tipper and no special care was taken. Where mixing was required (for the manure+trash and manure+trash+sawdust) it was carried out by the $1m^3$ bucket on the backhoe. This resulted in some pockets of unmixed manure and sawdust.

One windrow was cotton trash only, the second was 2:1 v:v trash:manure, and the third was 2:1:1 trash:manure:sawdust. For the mixed windrows, alternate bucket loads of feedstock were layered into each windrow using a front-end loader. Each pile was then turned, to mix the different feedstocks.

Initially the windrows were piled to a height of 2 m, with a basal width of 4 m. The width at the top of the windrow tapered to < 0.5 m.

Process control was achieved by manipulating the bulk density, watering and turning of the windrows. The critical control points were to maintain the core temperature of each windrow within the range of 45-65°C for as long as possible, and to ensure that all of the compost media was exposed to the elevated temperatures in the central core. Windrow turning occurred at the start of the trial, then every 5 weeks until the end of the active composting phase. The windrows were turned only once during the curing phase. The temperature of each pile was monitored twice weekly by inserting a temperature probe (stem 1 m in length) into the core region, at seven positions along the length of each windrow. The watering of the compost piles was managed to achieve as close to field capacity as possible, whilst avoiding leaching. Initially an inverted domestic soaker hose was placed along the length of the crest of each windrow. Water was jetted into the core of each pile for 45 minutes twice weekly. After 23rd August 1999 watering was automated to spray-irrigate two evenings a week, with two soaker hoses placed upright along the crest of each windrow. Water was supplied to both ends of the hoses, to regulate the pressure more evenly along the length of each windrow. The watering regime was adjusted by changing the settings on solenoid valves with electronic timers, with the volume applied logged on a 1 inch BSP domestic water meter (Fuzhou type MT-EX-D).

Watering and temperature data were analysed using a time series to chart the active and mature phases of composting. The water content, water holding capacity and bulk density of each windrow was assessed during the early (16th August 1999) and mid (8th October 1999) stages of active composting, prior to turning. Two intact cores were sampled from the core region of each windrow, approx. 0.5 m above the earthen pad. The field weight of each core was measured, and field capacity was approximated by applying 100 cm water suction (Loveday 1974). The cores were saturated for at least 24 hours using a blotting paper tray and capillary wetting. The cores were weighed, and placed on scintered glass funnels for the determination of water holding capacity at 50 and 100 cm water suction (4.91 and 9.81 KPa respectively). The dry weight of each core was determined by placing the cores in an oven set at 105°C for 24 hours.

4.4 Survival and activity of fusarium wilt pathogen

Stalks from harvested cotton plants known to be infected with fusarium wilt (*Fusarium oxysporum* formae specialis *vasinfectum* (Fov) were supplied by Dr J. Kochman, from a Queensland Department of Primary Industries (QDPI) disease nursery site (Brookstead, Qld). The stalks were shredded into <5 cm lengths using a rotary blade domestic shredder. Subsamples of 50 gm were placed into tulle mesh fabric bags 15 x 30 cm in area. On 16/8 four of the trash bags were buried at a depth of 50 cm below the crest of each windrow, and five were buried at a depth of 25 cm midway down the sides of each windrow (3 one side, two the other). One unburied trash bag sample was sent directly to the QDPI laboratory to assess the level of Fov infection at the time of burial, and one sample was stored under ambient laboratory conditions for the duration of the burial trial. The bags were recovered on 31/8, coincident with the first turning of the windrows. Both the buried and the unburied control bags were sent to QDPI for Fov analyses, under the supervision of Dr J. Kochman.

Trash remnants within each of the mesh bags were analysed using a direct plating technique and an indirect seedling bioassay technique. The direct plating consisted of surface-sterilising 50 randomly selected stem pieces per bag (placed in 70% ethanol and rinsed 3 times in sterile water), then placing them into potato dextrose agar plates amended with 0.5 g/L Streptomycin. The plates were incubated at approximately 250C and checked daily for evidence of fungal growth. The plates were discarded after 3 weeks. Results were calculated as the percentage of stem segments per bag (total 50) yielding colony identified as Fov. Contents of all of the 50 cm burial bags and all of the 25 cm burial bags for each windrow, were pooled for the seedling bioassays. Each of the pooled trash samples were mixed 50:50 v:v with potting mix, and placed into 25 speedling trays. One seed of the wilt-susceptible cultivar Siokra 14 was placed into each cell of the speedlng trays, and the seedlings were grown on for 8 weeks. At the end of 8 weeks, the percentage of seedlings showing wilt symptoms was calculated for the composted and uncomposted trash samples (total number of seedlings per treatment 25). Each wilted seedling was also directly plated onto the agar medium described above, to confirm that Fov was the causal agent.

At the same time that the trash bags were buried, cellophane strips dyed with remazol blue were also buried to assess the extent of cellulose decomposition (Moore *et al.* 1978). Dyed strips 2 x 5 cm in area were placed into tulle mesh bags and buried for 15 days, at the same relative positions within the compost windrows as the trash bags. Five dyed control strips were stored under ambient room conditions in the laboratory for the duration of the burial trial. After recovery the strips were rinsed to remove any adhering compost particles and any dissassociated dye. The

remaining bound dye was extracted, and the absorbance of the dye was measured using a spectrophotometer set at 595 nm. The percentage of cellulose utilisation was calculated by subtracting the average absorbance value of the treatment strips from the control, dividing by the control value and multiplying by 100. The control value was calculated as the average absorbance of the five unburied strips.

4.5 Chemical and biological indicators of compost maturity and quality

Three composite samples of the sawdust, cattle feedlot manure and cotton trash were commercially analysed (AGAL Pty. Ltd.). The samples were dried overnight at 30°C, ground and stored below 40°C prior to analysis. Total P and K were determined by x-ray flouorescence, total N by Kjeldahl, and total organic carbon by Walkley-Black (Rayment and Higginson 1992). Bicarbonate-extractable K, CaCl extractable P, and ammonium N, nitrate and nitrite N extracted with 2 M KCl, and total solids were also analysed. Values for each element were adjusted on an oven-dry basis (1050 C) as mg/kg of sample. A one-way analysis of variance (Systat software package) was used to compare the effect of adding different raw materials on the chemical composition of the composts.

Five samples collected along each of the three windrows (3 one side, 2 the other) were also chemically analysed. Each sample was taken after the windrows had been turned, coincident with the end of the active phase and into the mature phase of composting (weeks 15 and 20 respectively). All samples were stored in a cold room at 40°C prior to analysis. Each of the five samples per windrow was analysed as above. In addition the samples were analysed for total carbon (furnace method), labile (oxidised using 33mM KmnO4) organic carbon (Bell et al 1998), pH and electrical conductivity (Rayment and Higginson 1992). Results were analysed using a 2-way analysis of variance (Systat software package) partitioning for maturity and the different raw material mixtures.

The compost samples were also used to test the resin ion exchange method as an index of the rate of mineralisation of phosphorus. The gravimetric water content of five 10.00gm samples of each compost was also determined by oven-drying the samples overnight at 105°C. Samples were taken as described above, at weeks 10, 12, 14 and 18. 13.5 g of compost in the field state and 40 mL of water was placed in an end-on-end 50 mL volumetric shaker. Resin strips 62.5 mm x 25.0 mm in dimension (BDH anion exchange resin strips code 551642S) primed by stirring in 1 M NaCl for 2 hours were placed in each shaker prior to shaking overnight. The strips were removed, washed, and any bound P was desorbed by placing each strip in 40mL of 0.7 M NaCl and shaking for 2 hours. 10 mL of the desorbed solutions were analysed using an Autoanalyser and ICP-AES calibrated using standard P solutions. A two-way analysis of variance (Systat software package) was used to compare the effect of compost type and maturity on the mineralisation of P.

Compost samples taken at weeks 10, 14 and 18 were also tested for their microbial activity using the cellulose decomposition assay (Moore et al 1978). The bulk density values for compost samples taken on 8/10 were used to calculate the mass of compost to be packed into cylindrical PVC pipe sections (12.5 cm internal diameter, 16.5 cm long), with calico fabric secured over the bottom end. The three replicate pots (pipe sections) per compost type were interspersed into three

rectangular tubs, placed on a bench in a glasshouse maintained within a temperature range of 15 to 25°C. Capillary watering was maintained by topping up the reservoir of water as required, above the level of the 3 cm sand base in each of the three tubs. Five cellulose strips dyed with remazol blue (section AAA) were placed vertically to a depth of 10 cm in each pot. After 14 days burial the strips were recovered, washed and the amount of dye remaining calculated as outlined in the previous section. A two-way analysis of variance (Systat software package) was used to compare the effect of compost type and maturity on the cellulolytic activity of the microbes.

4.6 Assaying the mature composts for potential soil health benefits

A cotton soil with a history of fusarium wilt disease from the Brookstead region (Southeast Queensland, courtesy J Kochman) was used to test the potential impact of the composts on soil health. Three samples of the soil were assayed for total and available P and K, total, ammonium and nitrate/nitrite N, total C, Walkley-Black C, $KMnO_4$ C, solids, electrical conductivity and pH using the methods outlined previously (section BBB). Soil: compost mixtures 4:1 v/v were prepared by passing the media through a 5mm metal sieve. Recycled rubber fines (Australian Rubber Technologies 7 mesh fines) were added at the same volumetric ratio to the soil as the control. An inorganic salt mix (150 mg/kg KNO_3, 30 mg/kg gypsum, 10 mg/kg $ZnSO_4$) was added to each soil mixture to standardise the available macronutrient content. The available P content of each mixture was standardised by supplementing the inorganic P contribution of each compost to 300 mg/kg with $Ca(H_2PO_4)_2.H_2O$. Each soil mixture was placed into three free-draining styrofoam boxes (0.44 m long, by 0.25 m wide and 0.15 m deep). Initially the soil mixtures were capillary-watered to field capacity by placing each box in a plastic tray and maintaining a reservoir depth of 3 cm. The boxes were left to equilibrate for two weeks prior to planting, in a glasshouse maintained within 15-25°C.

Seed of a cotton variety known to be susceptible to fusarium wilt (Siokra 1-4) was pushed into the soil surface in four rows of six in each box. A 1-2cm layer of vermiculite was placed over the soil surface, to avoid disturbance during overhead watering. After the seedlings had emerged, the four rows per box were thinned to five seedlings. Emergence counts were recorded weekly, along with observations on seedling vigour and any evidence of disease symptoms. After 6 weeks in the glasshouse, the seedlings were rated for evidence of disease using a symptom severity rating from 0 to 5 (personal communication Wayne O'Neill Farming Systems Institute Qld. Dept. Primary Industries). Where possible sap from 10 symptom-free seedlings per box was analysed for sugar content using a refractometer. The youngest fully expanded leaf on each seedling was removed from the plant and placed in a garlic crusher to produce several droplets of sap. The sap was placed on the prism of the refractometer and the sugar content was recorded in Brix units. A one-way analysis of variance (Systat software package) was used to test if the compost mixtures enhanced the circulating carbohydrate (sugars) content of the plants. The pathogen status of diseased plants was confirmed by placing sections of the stem of affected plants onto 1/5 strength potato dextrose agar amended with streptomycin. Plates were incubated at 20°C for two weeks and scored for the presence of wild-type colonies of Fov. The compost associated with the greatest improvement in plant health in the fusarium assay was then tested for efficacy in a cotton soil known to be infested with verticillium wilt, using the same methods as described above.

5. Results

5.1 Survey of gin trash

5.1.1 Pesticide residues

No PCB's or organo-phosphates were detected in any sample.

All of the samples from the composting sites were found to contain measurable amounts of DDE.

Site	C1	C2	C3
DDE concentration (ppm)	0.1	0.1	0.17

DDE is a non-insecticidal, biologically active breakdown product of DDT (Corbett *et al.*, 1984). The most likely explanation for this result is that the composting in each case is taking place on soil that has previously had DDT applied and that a sufficient amount of time has passed since this application took place for the DDT breakdown products to be present but not the DDT.

All of the samples from the gins were found to contain measurable amounts of endosulfan.

Site	T1	T2	T3	T4	T5	T6	T7	T8	T9
Endosulfan concentration (ppm)	1	1	1	0	1	0	0	0	0.1

Endosulfan has clearly persisted in the (uncomposted) cotton trash, even late into the harvest and ginning season in this case.

In addition, sample T1 had measureable levels of Endrin, a chemical from the same family as Dieldrin, Chlordane, Heptachlor, Aldrin, and Endosulfan.

Site	T1
Endrin concentration (ppm)	0.2

5.1.2 Cotton Pathogens

The seedlings in the composted trash/potting mix blend (predictably) grew more quickly and appeared more healthy than those growing in the raw trash/potting mix blend. The latter seedlings were usually somewhat stunted and nutritionally deficient.

Sample T1 was found to have high levels of Rhizoctonia and Alternaria fungus, which are

commonly associated with seedling diseases when present at high levels.

Sample T5 was found to contain high levels of a fungus from the Fusarium genus but not pathogenic to cotton.

Samples T6 and T7 were found to contain high levels of Alternaria fungus, which is commonly associated with seedlings diseases when present at high levels.

Sample C3 was found to contain high levels of a fungus from the Verticillium genus but not pathogenic to cotton.

The presence of fungus other than FoV and Verticillium in the trash samples is a reflection of the fact that some of the gins had been finished for the season for a period of weeks. The trash was therefore already in the early stages of slow biological breakdown process that takes place naturally in dumped piles of gin trash.

The absence of pathogenic FoV and Verticillium in the trash samples may be explained by the mode of action of the fungi, which are more likely to be present in the main vascular part of the plant rather than in the leaf, stick and bract that is commonly included in gin trash.

5.2 Practical results

It was expected that the trash would be difficult to wet, due to the hydrophobic nature of the lint component that has a naturally water resistant cuticle. It was therefore initially decided that watering would be via soaker hose laid upside down to jet water into the apex of the windrows at a low rate of 29 litres per minute along the length of each 27m windrow. Over the first six weeks about 15L/day of water was applied per cubic metre of material.

It was found that the water was not being distributed to all parts of the windrows even when it was applied for long enough periods that it began to pool at the base. The water was found only in a narrow vee beneath the apex.

The water was then applied with the soaker hoses laid the right way up to broadcast the water. The problem of drift and evaporative losses during warm and windy days was addressed by using solenoid valves and an electronic timer to turn the water on for set periods during the early hours of the morning.

During week 7 water application was increased to 68 L/m^3/day. After week 7 wateriug was reduced to approximately 37 L/m^3/day.

Infiltration was improved when the hoses were placed upright. This coincided with an elevation in the temperature of the windrows (**Figure 1**). An increase in the bulk densities and field water contents over the first ten weeks of composting reflect the improved watering regime (**Table 2**). Over the first fortnight (16/8/'99), field water contents and field capacity approximations were similar for all three windrows, despite differences in the bulk densities. As expected, the addition of feedlot manure to the trash increased the bulk density, concomitantly increasing the water holding capacity of the mixture once adequate infiltration had been achieved. By the second

turning (8/10/'99) the volumetric water content of the trash-manure mixture was 50% greater than that of trash only (0.51 and 0.33 cm^3/cm^3). Given that the bulk density of sawdust is similar to cotton trash, the difference in water holding capacity between trash only and the sawdust mixture was marginal (0.32 and 0.38 cm^3/cm^3 respectively).

Despite the higher bulk density in the trash and manure windrow, there was still sufficient aeration to maintain temperatures within the preferred range of 45-65^{0}C (**Figure 1**). From week 5 to week 15, the temperatures recorded in all three windrows were consistently within the optimal range. At no time did the maximum temperatures recorded within all three windrows exceed 70^{0}C. Reductions in the temperature of the windrows to below 45^{0}C only occurred after the third turn (week 15, 15/11/'99).

	Compost sampled 16/8/'99			**Compost sampled 8/10/'99**		
	Trash only	**T+manure**	**T+manure + sawdust**	**Trash only**	**T+manure**	**T+manure + sawdust**
16/8/99						
Field state	0.33	0.18	0.13	0.30	0.49	0.31
(cm^3/cm^3)	0.16	0.35	0.39	0.36	0.53	0.48
100 cm						
suction	0.18	0.19	0.15	0.28	0.47	0.30
(cm^3/cm^3)	0.34	0.31	0.36	0.36	0.51	0.47
bulk						
density	0.16	0.27	0.25	0.18	0.40	0.12
(g/cm^3)	0.22	0.30	0.24	0.25	0.41	0.16

Table 2. Change in bulk density and water bolding capacity over time. Windrows were sampled at weeks 2(16/8) and 10(8/10/'99). Results of two cores per windrow are given.

5.3 Temperature time series data

Figure 1 shows the effect of this change on the temperatures within the windrows.

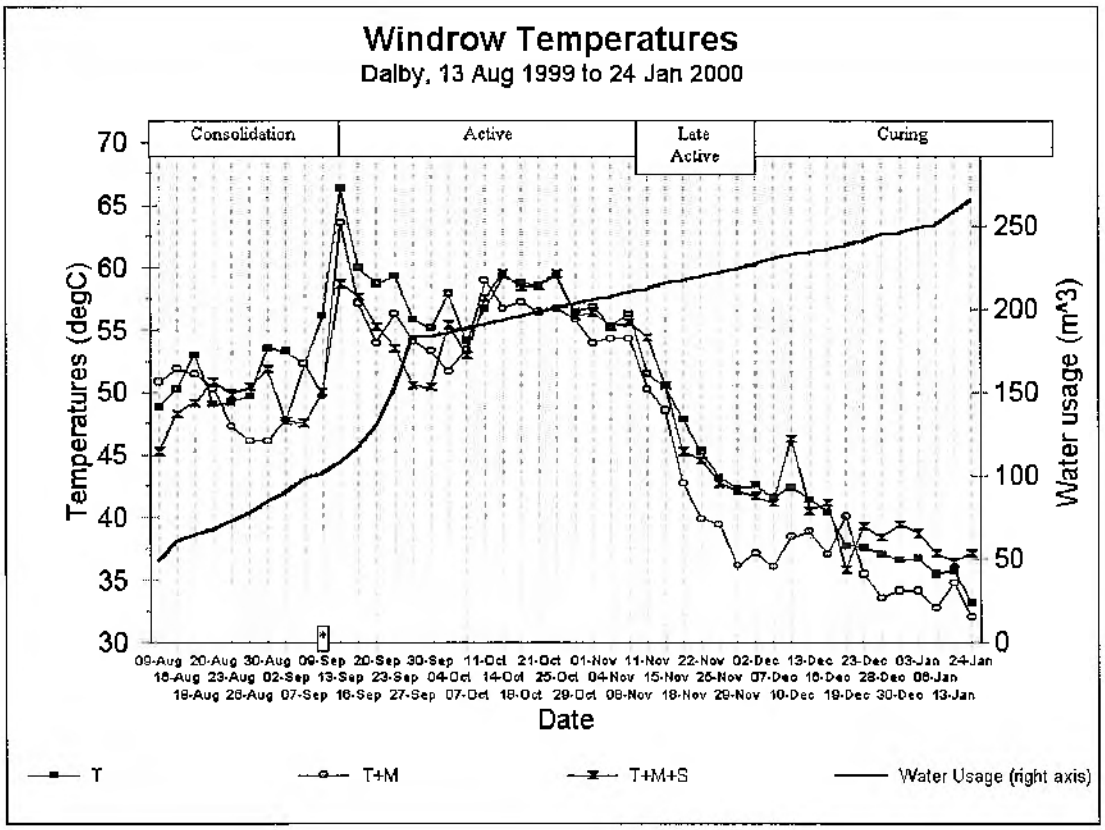

Figure 1 - Temperature of each windrow over composting cycle

The asterisk near the date of 9th Sept 2000 shows the time at which the change to the method of applying water was made and the entire windrows became fully watered across their cross-sections.

Figure 1 also shows the four distinct stages in a typical compost process. Initially, trash is very dry due to the nature of the cleaning and transport process in a gin. The windrows consolidate as they become moist, and the temperature rises, particularly as the water becomes fully distributed. This is termed the consolidation phase.

The temperature reaches a plateau when the heat produced by the composting micro-organisms limits their own activity. This plateau is usually between 55°C and 65°C. This is termed the active phase.

The process then continues while the readily metabolizable material is converted. In this case there is a small dip around 30th Sept 1999 when the material become saturated and oxygen became limiting.

Eventually the readily metabolizable material starts to become exhausted, and the temperature starts to drop as the rate at which the material is oxidized drops. This is termed the late active

phase.

When the readily metabolizable material is exhausted, the temperature within the windrows declines at a slower rate. Microbiological activity is still going on, but the material is now relatively stable humus. This is termed the mature phase.

The kinds of microorganisms within the windrow are also changing. There is a decline in some of the populations that were very active during the active phase. The nutrients that were locked up in their cell structures are now available to other microorganisms and are broken down to their mineral forms. As a result, these nutrients are now available to plants. The longer the mature phase continues, the more these nutrients become available.

5.4 Survival and activity of fusarium wilt pathogen

The Fov infested trash bags and the remazol cellulose strips were buried during the marginal phase of active composting (weeks 2 to 4). During this time the water content of the windrows was less than optimal, resulting in suboptimal microbial activity and a suboptimal temperature (**Figure 1**). The core temperatures recorded over this period, were within the range of 45-55^{0}C in all windrows (**Figure 1**). The cellulolytic activity in the core region of each of the windrows was only 24-30%, with negligible activity (<1-7%) in the outer 25 cm zone (**Table 3**). Mulching the cotton stalks and storage for two weeks under ambient room conditions reduced the survival of Fov in the stems from 42% to 14%. When the unburied, mulched trash was added to potting mix in the seedling bioassay, 70% of the seedlings showed wilt symptoms and were positive for Fov (**Table 3**).

Table 3. Percentage recovery of Fov from infested trash segments buried for two weeks in the windrows, and from susceptible cotton seedlings grown for eight weeks in a trash and potting mix medium. Utilisation of cellulose over this time is also given.

	Unburied control	Composted 25cm depth			Composted 50cm depth		
		Trash	T&M	T&M&S	Trash	T&M	T&M&S
stem pieces	14%	0%	0%	0%	0%	0%	0%
seedlings	70%	0%	0%	0%	0%	0%	0%
cellulose utilisation	0%	7%	2%	<1%	24%	30%	27%

T&M= trash and manure T&M&S= trash and manure and sawdust

Despite the lowered temperatures, burying the mulched trash in the compost piles both at depths of 25 cm and 50 cm reduced the survival of Fov to undetectable levels. Similarly the reduction in survival was mirrored by no evidence of wilting symptoms in any of the compost mixtures in the seedling bioassays. Thus despite the suboptimal water content and microbial activity in the windrows, the temperature elevation was sufficient to effectively disinfect the buried cotton stalks.

5.5 Chemical and biological indicators of compost maturity and quality

Over the duration of composting the organic carbon (Walkley/Black) content of the trash had reduced progressively from 30.4% to 22.7% to 20.8% (**Tables 4 and 5**). This loss of biomass was evident in the contraction of the length of the windrows from 35-24 m, 36-27 m and 35-24 m respectively for the trash, trash and manure and trash, manure and sawdust composts. Despite the statistically significant differences in the organic carbon content of the raw materials (**Table 4**), by the end of composting all windrows had organic carbon levels of about 20 % (**Table 5**). The C:N ratio was highest in the trash, manure and sawdust mix (10). The lowest was in the trash and manure compost (8), reflecting the higher total nitrogen content. As expected, the addition of manure increased the concentration of total and available P, but differences between the windrow mixtures for total and available K and total N were either not significant or only marginally significant. Given that a comparatively large proportion of the N in the manure was in the ammonium form (**Table 4**), it is possible that losses via volatilisation may have occurred during the early stages of composting. This phase coincides with suboptimal water availability in the windrows, which limited microbial activity (compare % cellulose utilisation given in **Tables 3 and 7**) and therefore limited the potential 'tie up' of all of the nitrogen.

	Total P	Mineral P	Total K	Mineral K	Total N	NH_4	nitrate/ nitrite	Walkley /Black C (%)
Cotton trash	1277 (102)	470	16333 (2023)	13933 (2205)	17000 (1000)	313 (116)	67.3 (17.1)	40.6 (4.4)
Feedlot manure	5960 (267)	1023 (126)	20800 (1510)	16800 (2193)	24333 (1155)	1533 (231)	2.3 (0.1)	24.2 (2.2)
Cypress sawdust	11.6 (2.5)	2.1 (0.8)	487 (15.3)	293 (143)	1200 (0)	163 (32.2)	<1	30.4 (1.4)
statistical significance	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001

Table 4. Chemical analyses of the raw feedstock used in the windrows. Unless otherwise indicated, all values are mg/kg on an oven-dry basis. Standard deviation associated with the mean is in brackets. Results of the probabilities for a one-way analysis of variance comparing nutrient contribution from the raw materials is also given.

Available P and available N (ammonia, nitrate and nitrite N) actually decreased in concentration relative to the original feedstocks during the active phase, becoming bound in the microbial biomass. As expected, the microbial activity reduced as the composts matured, increasing the levels of available P and nitrate (mineralisation: **Figure 2**). Despite statistically significant differences in the total and available K contents of the raw materials, the results for the active and mature composts were not significantly different (**Tables 4 and 5**).

Given that K is primarily a constituent of the cytosol of cells and is readily leached (Marschner 1997), this lack of significance is to be expected. The only living cells sequestering the K are microbial in origin, and any differences in the labile (microbial) organic carbon fractions in the composts were not statistically significant **(Table 6 and Figure 3)**.

	Total P	Mineral P	Total K	Mineral K	Total N	NH_4	nitrate/ nitrite	W/Black C (%)
Active Trash only	2406 (337)	142 (74)	13880 (8050)	12260 (1834)	25000 (5958)	36.6 (20.5)	53.5 (53)	22.7 (3.0)
T& Manure	3682 (675)	374 (309)	15680 (2287)	12620 (1725)	22600 (3647)	256.2 (120.2)	43.2 (66.7)	22. (3.3)
T&M& Sawdust	2646 (378)	142 (59)	14146 (4193)	11460 (3679)	19000 (2916)	203.2 (116.1)	41.96 (64.2)	21.5 (2.9)
Mature Trash only	3116 (479)	1120 (215)	13320 (1684)	10990 (1338)	24200 (4494)	35.8 (32.2)	457.8 (409.2)	20.8 (2.8)
T& Manure	4984 (812)	1962 (414)	15020 (1580)	12400 (1541)	21800 (3420)	204.8 (127.3)	353.4 (405.1)	17.5 (2.4)
T&M& Sawdust	2846 (895)	1328 (514)	12480 (2208)	9320 (2645)	18600 (3209)	163.8 (93.7)	214.2 (266.2)	19.4 (5.5)
Significance feedstock	<0.001	0.002	0.251 (ns)	0.134 (ns)	0.014	<0.001	0.561 (ns)	0.425 (ns)
Significance maturity	0.004	<0.001	0.099 (ns)	0.158 (ns)	0.658 (ns)	0.388 (ns)	0.005	0.036

Table 5. Chemical analyses of the compost windrows sampled at weeks 15 (end active phase) and 20 (mature). Unless otherwise indicated, all values are mg/kg on an oven-dry basis. Standard deviation associated with the mean is in brackets. Results of the probabilities for a two-way analysis of variance are also given. The abbreviation ns in brackets indicates where results are not statistically significant below the 0.05 level. Results for the interactive term (maturity x feedstock) are not included, as none were significantly different.

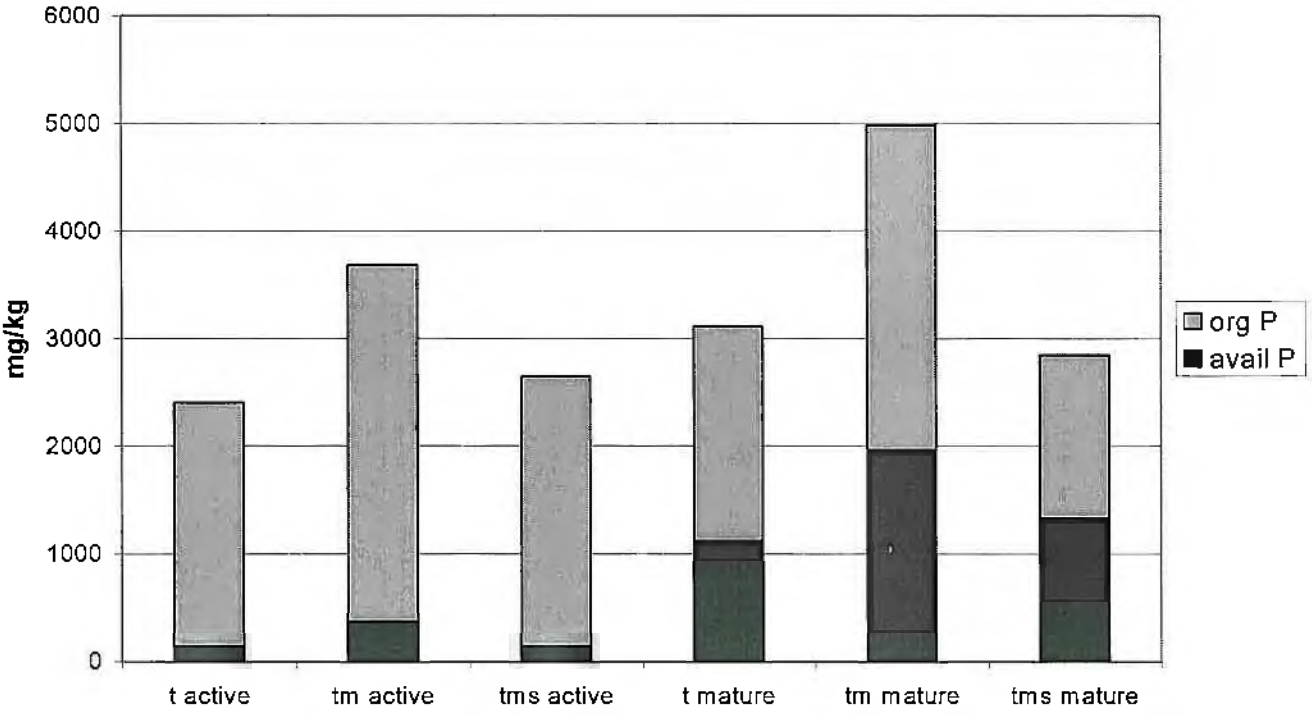

Figure 2. Mineralisation of P (available P) in the three composts at the end of the active (week 15) and the mature (week 20) phases. T=trasb, m=manure, s=sawdust.

	Total carbon %	W./ Black carbon %	$KMnO_4$ carbon %	Solids %	EC mS/cm	pH
Active Trash only	29.6 (5.5)	22.7 (3.0)	3.62 (0.80)	94.8 (0.9)	5.01 (0.93)	8.2
T& Manure	26.0 (4.6)	22 (3.3)	3.54 (0.64)	95.1 (0.6)	5.26 (1.45)	8.0
T & M & Sawdust	24.2 (3.2)	21.5 (2.9)	3.16 (0.86)	91.6 (6.5)	3.7 (0.33)	8.3
Mature Trash only	28.3 (5.5)	20.8 (2.8)	4.1 (0.4)	67.9 (11.3)	2.96 (0.40)	8.5
T& Manure	21.0 (6.0)	17.5 (2.4)	3.05 (0.52)	74.6 (8.4)	3.78 (0.36)	8.4
T & M & Sawdust	23.1 (2.3)	19.4 (5.5)	3.44 (0.63)	85.7 (7.5)	3.58 (0.63)	8.5
Significance feedstock	0.026	0.425 (ns)	0.369 (ns)	0.086	0.063	
Significance maturity	0.167 (ns)	0.036	0.329 (ns)	<0.001	<0.001	
Interactive term	0.595 (ns)	0.653 (ns)	0.389 (ns)	0.008	0.034	

Table 6. Chemical analyses of tbe compost windrows sampled at weeks 15 (end active phase) and 20 (mature). Unless otherwise indicated, all values are mg/kg on an oven-dry basis. Standard deviation associated witb the mean is in brackets. Results of the probabilities for a two-way analysis of variance are also given. The abbreviation ns in brackets indicates where results are not statistically significant below the 0.05 level.

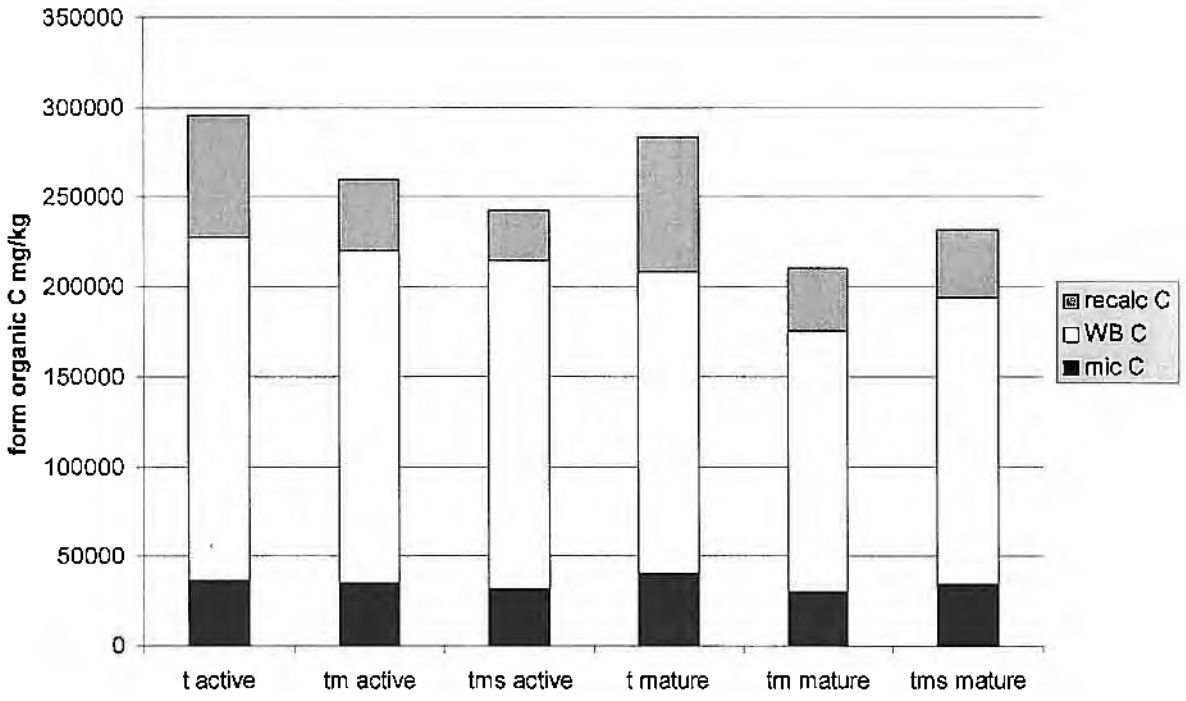

Figure 3. Labile (microbial), Walkley/Black and recalcitrant organic carbon fractions for tbe three different compost windrows sampled at 15 and 20 weeks.

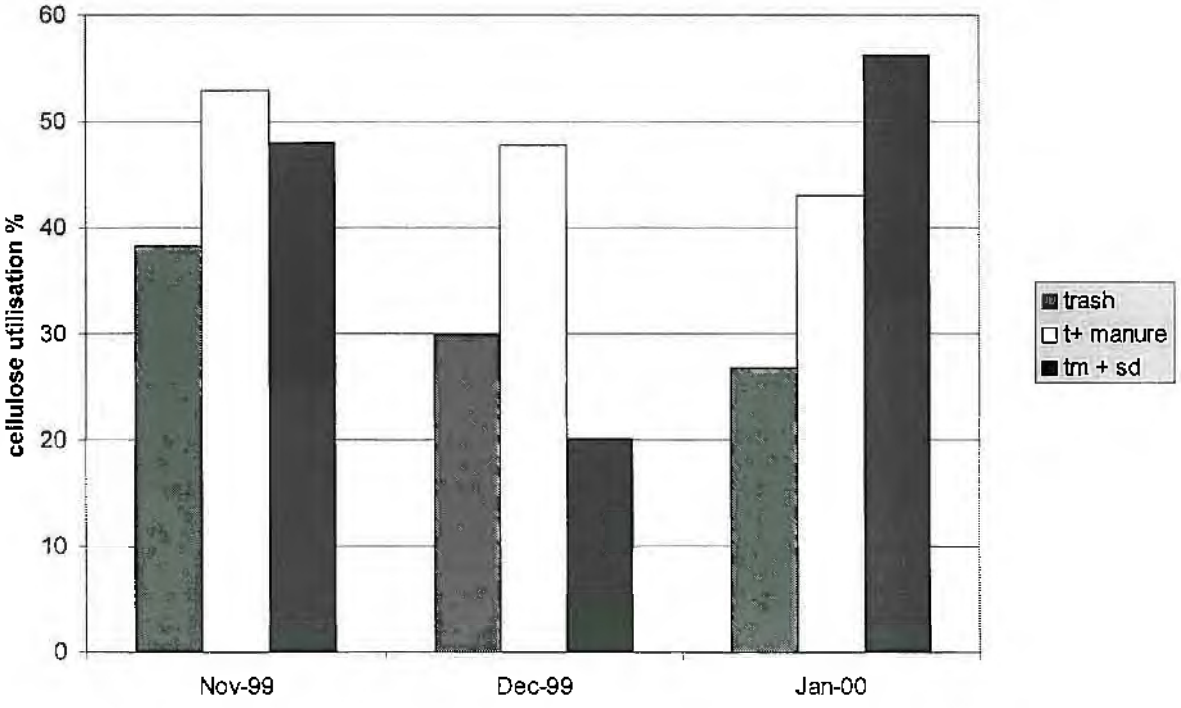

Figure 4: Percentage cellulose utilisation in compost cores incubated for 2 weeks in in the glasshouse. T = trash, m = feedlot manure, sd = cypress sawdust.

	Compost sampling date for dye (absorbance) and P (mg/kg) assays			
	15/11	**29/11**	**13/12**	**11/1/00**
	absorbance	**absorbance**		**absorbance**
Trash only	0.338 (0.065)	0.421 (0.072)		0.440 (0.047)
Trash + manure	0.258 (0.032)	0.313 (0.067)		0.343 (0.067)
T+M+ sawdust	0.285 (0.068)	0.480 (0.201)		0.263 (0.066)
	P mg/kg	**P mg/kg**	**P mg/kg**	**P mg/kg**
Trash only	2.870 (3.374)	1.782 (0.886)	0.900 (0.684)	2.248 (1.373)
Trash + manure	4.851 (3.901)	5.330 (3.142)	2.324 (1.824)	2.721 (0.871)
T+M+ sawdust	6.184 (5.988)	2.530 (1.844)	4.631 (3.518)	2.513 (0.978)

Table 7: Changes over time in the residual dye remaining in the cellulose strips (absorbance units) and in the mineral phosphorus extracted from the resin strips (mg/kg compost mix). Standard deviation of the mean is in brackets.

source	P value 15/11 sample	P value 13/12 sample	P value 11/1 sample
feedstock	0.005	<0.001	<0.001
tub	0.020	0.326	0.490
interaction	0.078	0.003	0.395

Table 8: Summary of the probabilities of the two-way analyses of variance for absorbance of the residual dye in the cellulose strips. Variance was partitioned into the compost feedstock and the tubs in which the cores were placed for capillary watering. Data for each sampling date were analysed separately.

With respect to the three carbon fractions analysed, total carbon (including the biologically unavailable fraction) was marginally higher in the trash only sample (P= 0.026), but there was no difference between samples taken at the end of the active phase and the mature phase (**Table 6 and Figure 3)**). In contrast the acid-oxidisable carbon fraction (Walkley-Black) reduced marginally (P= 0.036) in all three composts from the end of the active phase to the mature phase. There were no significant differences in the labile ($KMnO_4$) carbon fractions of the three composts (feedstock), nor any significant changes over time.

However despite the lack of or only marginal significance of the organic carbon results, the microbial activity (as indicated by the remazol blue cellulose assay) consistently showed differences between the feedstock (**Tables 7 and 8**). Adding manure to the compost significantly increased the cellulolytic activity ($P \leq 0.005$) relative to the trash only compost. In ocntrast the influence of the tubs used to capillary water the compost cores was marginally significant (P= 0.020) for only the first sampling date. When the results for the compost cores within the three tubs were pooled, changes over time, differences between the feedstock and the interaction of the two were highly significant ($P < 0.001$). Over the three sampling dates the trash and manure mix had consistently higher cellulolytic activity relative to the trash only, and both mixes reduced in activity over time (**Figure 4**). This may explain the earlier reduction in temperature in the windrow temperature profiles apparent in **Figure 1**. Results for the trash, manure and sawdust mix were erratic, reflecting the difficulty encountered in mixing the feedstocks adequately (**refer seetion CCC**).

The reduction in cellulolytic activity over time reflected the increase in maturity of the composts. However results for the resin P extractions, tested on all three of the samples used for the cellulose assay, were extremely inconsistent (**Table 7**). Standard deviations around the mean were large, indicating the high variation recorded in the five replicates analysed. Results for the two-way analysis of variance partitioning for maturity and feedstock yielded no significant differences below the P=0.05 level. Unfortunately the resin P method failed to reflect the changes in the maturity of the composts over time. The reduction in cellulolytic activity (**Table 7**), the increase in available P (**Table 5**), and the decrease in electrical conductivity (**Table 6**) were better indicators of compost maturity.

5.6 Assaying the mature composts for potential soil health benefits

The chemical analyses of the two soils indicated that both have a neutral pH (6.9-7.6), and both chemically bind potassium leaving very little available for plant growth (**Table 9**). Only two of the three replicates were used to present the verticillium soil data, as the results for the third were at least one order of magnitude greater for total N, Nox, Walkley/Black and $KMnO_4$ C, and electrical conductivity. These results suggest that the sample analysed was from manure, and not the soil itself. Therefore no standard deviation was provided for the two samples used.

The labile fraction of organic carbon was similar for both soils (0.15 and 0.17 % for the fusarium and verticillium soils respectively), but the verticillium soil had twice the concentration of acid-oxidisable (biologically available) carbon (**Table 9 and figure 5**). Indeed most of the carbon in the fusarium soil was in the recalcitrant fraction, considered biologically inert (possibly charcoal in origin: Moody et al 1997). The labile carbon fraction in soil is highly correlated with key physical and chemical properties (Bell et al 1998). The labile fraction of the composts is an order of magnitude greater than that of the soil (ranging from 3.44 to 4.10%), and the Walkley-Black fraction is two orders of magnitude greater (ranging from 0.46 to 0.97% for the soils, and from 17.50 to 20.80% for the composts). Accordingly the addition of compost at a volumetric ratio of 1:4 to the soil will substantially improve the available P, K and the biologically available organic carbon levels for seedling growth and soil health.

Completion of the fusarium bioassays has been delayed due to poor viability of the seed initially sown. A new source of seed has been re-sown. Growth is also slow because the night temperatures are just above 15°C in the glasshouse. Space in the glasshouse and ready access to the verticillium soil (from ACRI at Narrabri) precluded undertaking the assays at the same time. The results of the fusarium soil assay will be used to select the most active compost to repeat the soil health bioassay with the verticillium soil. Results will be sent after completion of the bioassays. Any outstanding costs will be met by the Agwise project.

	Phosphorus mg/kg	**Potassium mg/kg**	**Nitrogen mg/kg**	**Carbon %**
Fusarium soil				
total	267 (50)	2840 (491)	1027 (64)	1.36 (.05)
available	73 (35)	510 (20)	47 (34)	0.46 (0.11)
Verticillium				
soil total	995	6760	1700	1.56
available	145	805	38	0.97

Table 9: Mineral characterisation of the fusarium and verticillium wilt soils used for the soil health bioassays. Results for the ammonia and nitrate/nitrite nitrogen were added to provide the available N data. The Walkley/Black carbon values were used for the available C data. Standard deviation is in brackets.

6. Discussion

6.1 Composting and the maintenance of local quarantine and hygiene

The survey of pesticide residues in trash sampled from nine cotton gins towards the end of the 1999 season indicates that only Endosulfan poses a potential hazard to users of cotton trash (Table 1). The concentrations measured in this survey are likely to be an underestimate, given that the trash samples were from late in the season. In Australia ginning starts earliest in the northern regions (ie Emerald), becoming progressively later at locations further south. However this was not reflected in the concentrations recorded. Evidence suggests that composting is effective in reducing the activity of Endosulfan (a critical control strategy). This pesticide was below detectable levels in all three of the composts tested. However DDE was detected in all three composts, but not in the gin trash.

Both DDT, Endosulfan and DDE are organochlorine compounds, known to persist in the environment. However DDE is the non-insecticidal product of the dehydrochlorination of DDT and related compounds (Corbett *et al.* 1984). Most likely soil contaminated with DDT was incorporated into the compost windrows during turning. That only DDE was detected, indicates that the composting process is effective at deactivating organochlorines such as DDT and Endosulfan, minimising their potential environmental impact.

The elevated temperatures commonly occurring in windrows during composting also appear to be very effective at destroying the activity of plant pathogens such as Fov (Table 2). The infested stalk samples used in these experiments were only subjected to an average temperature of 45-500C for a fortnight, yet disinfection was complete. Microbiological disinfection standards for composting specify that the temperature within windrows should be in the range of 55-600C for a day or two (Haug 1993). The watering regime, selection of compost feedstocks and windrow management used in these experiments maintained core temperatures within this range for several weeks (Figure 1). Provided that the turning regime of the windrows ensures that all portions of the compost are exposed to the elevated core temperatures, composting has the potential to effectively disinfect both plant and animal pathogens. Moreover at these temperatures, most weed seeds should be destroyed as well (Powles *et al.* 1988). However in our experience, turning the windrows with a front-end loader does not guarantee a uniform mixture. Where possible, at least the initial mixing of compost feedstocks should be done with a back-hoe bucket. An experienced operator can then selectively grab sections of poorly mixed feedstock, dispersing it over a larger area of the windrow. Self-propelled machines capable of inverting compost feedstocks into the centre of windrows have been developed in Australia for the mushroom industry, but the capital outlay is of the order of $150,000.

6.2 Process controls in composting

The mechanism of thermophillic heat disinfection within soil and composts has two key components. One is direct exposure to lethal heat, the other is competitive exclusion by the

activities of antagonistic bacteria (Hellmann *et al.* 1997). However bacteria require high levels of available water for activity. At lower water activities, thermophillic storage fungi such as *Aspergillus fumigatus* may predominate (Madigan *et al.* 1997). In most engineering handbooks on composting, the figure of 60% wet weight is often referred to as optimal for microbial activity (for example Haug 1993). However the water holding capacity of potential feedstock is highly variable as is the bulk density of windrows of different heights. Therefore the specification of one water content (ie 60%) is illogical given the potential range of water holding capacities of different composts. For example in straw-based mushroom windrows and timber–based potting media windrows of moderate height, water contents of closer to 70% are recommended for optimal microbial activity (Harper *et al.* 1992, Inbar *et al.* 1988).

From a practical point of view, the water content of a compost mix at the field capacity approximation should be used as the upper limit. Above this limit, water will percolate from the windrow, increasing the potential for nutrient leaching and odour production (Ulen 1993). Monitoring the temperature profile within the windrow will indicate if there is too little or too much resistance to heat transfer. In our case, windrow heights of 1.5 m and bulk densities of 0.2 to 0.4 g/cm3 maintained the temperature within the optimal range, without the need for frequent turning. Indeed our recommendation for a minimum of three turns during the first 15 weeks of composting is to maximise the likelihood that all components of the windrow will pass through the central core, not for temperature control.

After optimal water contents in the mixtures were achieved, all three windrows supported sufficient microbial activity to elevate core temperatures above 55°C (Figure 1). The composting process was faster in the trash and manure mixture, with the temperature decline at the end of the active phase occurring several weeks ahead of the other mixes. Given that microbial activity has reached the stationary phase more quickly, the extent of mineralisation should also be more advanced in this mix. This is evident in the higher microbial activity (Figure 4), and the higher ratio of available to total P in the trash and manure mix (Table 5). The rate of decomposition in the trash, sawdust and manure mix was expected to be slower, given that much of the cellulose in the sawdust fraction is more difficult to metabolise. Sawdust was added to the mix, as the degradation products of the phenolics in bark and hardwoods are known to control some soilborne diseases (Hoitink *et al.* 1991). However the tough 'recalcitrant' carbon fraction in the trash only feedstock was even higher than that of the sawdust mix, with the potential to improve disease control. Bioassays will be conducted on these mixtures to evaluate any disease-suppressive properties.

6.3 Indicators of compost maturity and determining rates of application

The addition of manure to the compost mix increased the P content, with more marginal increases in K and N (Table 5). The advantage of using a compost as a fertiliser over traditional inorganic NPK fertilisers is that organic carbon and microbial populations are added, and that the bulk of the nutrients are present in a slow-release form (Smith *et al.* 1998). Moreover manure feedstocks are a very useful source of trace elements (McCalla 1974). However the slow-release nature of composts complicates the accuracy of scheduling applications to soil, needed to optimise plant growth and to minimise nutrient leaching. Analysing the total and available nutrient composition

of a mature compost will indicate the application rates required for good, early crop growth, but gives no indication of the rate of release and carry-over for the season. We had hoped that the ion exchange resin P test would provide a quick, relatively inexpensive method for estimating the mineralisation rate of composts. Unfortunately the high variation encountered between the five replicates analysed is too inaccurate to be of any practical use (Table 7). Indeed microbial activity and therefore the potential rate of mineralisation was higher in the trash and manure mix, but this was not reflected in the resin P results. Therefore conventional soil tests for inorganic and total P still provide the best practical index of compost maturity (Table 5).

Traditionally organic amendments such as composts are applied to soil on the basis of their total nitrogen content. However the process of composting locks up mineral N and P into the microbial biomass, with mineralisation occurring only as the compost matures (Tables 4 and 5, figure 2). Application of immature composts to soil will result in very little of the N and P being available for plant growth. As a consequence, inorganic fertilisers must be applied to meet the early growth requirements of the crop. Given that to date there is no accepted test for determining the rate of mineralisation of composts, the potential exists for excess nutrients to accumulate in the soil over time As the rate of nutrient release is uncontrolled, the potential for uncontrolled growth flushes in the crop is also increased. However if composts are managed to the point where about 50% of the P is in the mineral form and assuming that 80% of the total K is available, then the rate of compost application can be adjusted to meet the P and K requirements for early crop growth. In practical terms the cost of inorganic fertiliser inputs for super phosphate and muriate of potash can be offset by scheduled compost application, with the risks of nutrient pollution in the environment minimised. Soil tests for available N, P and K taken at the start of the next cropping cycle can then be used to aadjust the amount of conventional inorganic fertiliser required for the crop.

The use of composts on the basis of circa 50% inorganic P content not only reduces the potential for nutrient pollution, but also promotes the activity of beneficial microorgamisms including mycorrhizae. The chemical analyses of the two cotton soils used in the soil health bioassays shows that they are very low in organic matter, and low in available N, P and K. The labile carbon fraction of the composts is one order of magnitude greater than that of the soils and the Walkley-Black fraction is two orders of magnitude greater (Tables 6 and 9). Therefore the addition of composts such as these to soils depleted in their organic carbon content has the potential to substantially improve soil health (Follett 1987). Cotton is considered to be moderately dependent on mycorrhizal infection for healthy plant growth (Glendinning 1999). High concentrations of available P are known to inhibit the colonisation of roots by mycorrhizae. Therefore mycorrhizal colonisation and soil health generally will be improved by high rates of application of a mature compost, provided that the availability of P is controlled. We await the results of our fusarium wilt bioassays, for evidence of differences in the disease control properties of the three compost mixes.

7. Conclusions and Likely Impact of Research

This project has answered the primary questions that underlay its initiation. We now have basic information on what is in typical Australian cotton trash, including:

- chemical makeup;

- synthetic chemicals;
- cotton pathogens and other microorganisms.

We also have an indication of the practical measures that can be used to take trash and produce compost with known attributes. These practical measures were put together with a firm emphasis on minimizing time and cash inputs, in the belief that this would make adoption of trash composting as painless as possible to ginners and so more likely to occur.

One of the impacts of this project therefore should be that the ginning industry now has a alternative to stockpiling. Composting has of course been a 'known science' in general terms for some time now, but this project has demonstrated composting in a working gin setting using an approach that ginners themselves might have used.

The industry now also has some firm numbers on pathogen and synthetic chemical removal, under composting practice that takes steps to ensure that removal is best facilitated.

The cotton industry in general also now has another source of organic carbon to replace that lost under most forms of intensive cultivation, and a concentrated and varied source of associated microorganisms that are necessary for good soil health.

8. Project Technology

There were no patents or licenses applied for or granted during this project.

The commercial significance of this project lies in its emphasis on easing the process of adopting relatively well established composting practices, and adequately specifying the output.

8. Publications arising from this project

Pittaway P, Roberts DG, *Low Technology Methodology for Composting Cotton Gin Trash*, proc. 2000 Society for Engineering in Agriculture conference, Adelaide, March 2000

Pittway P, Roberts DG, *Compost Processing Organic Waste for Recycling*, proc. International Seminar on control of greenhouse gases in agriculture, University of Queensland Gatton campus, Gatton, 26th - 27th June 2000

Roberts DG, Pittaway P, *Low-tech gin trash composting to remove pathogens and residues*, proc. 10th Australian Cotton conference, Brisbane, August 2000

Pittaway P, Roberts DG, *Maximising Low-Tech. Cotton Trash Composting for On-Farm Use*, National Centre for Engineering in Agriculture, Toowoomba, Sept 2000

Roberts DG, Pittaway P, *Guide for composting gin trash on-site*, National Centre for Engineering

in Agriculture, Toowoomba, Sept 2000

On Sept 28th - 29th 2000, Dr Pam Pittaway was invited to present a paper to and speak at a seminar for the Dawson AgroForestry Group Inc. at Theodore, titled *Cotton trash, Composting and Agroforestry*, outlining the application of this project to the local production of potting media for a local tree seedling nursery.

Pittway P, 2000, *Optimising the re-use of rural organic waste in agriculture by composting*, Journal of Soil Science (abstract submitted Sept 2000)

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