C 2000

Part 1 - Summary Project Details

Final Report

Report Due Date:	29-Sept-00	CRDC Project Number	SPC1C
Project Title: (< 15 words)	Composted Organic Wastes as a Soil Amendment for Sustainable Cotton Production		

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PART 3 – FINAL REPORT

1. Outline the background to the project

The importance of soil organic matter for the maintenance of soil structure, and the efficient use of water and nutrients is widely recognized. Industry-funded research projects are currently investigating the management of soil organic matter in cotton-growing soils.

Vermicompost - Worm-composting of organic residues from animal and plant processing produces a finely-divided organic material, vermicompost, which is reputed to produce superior growth-responses in plants. Edwards & Neuhauser (1988) and Buckerfield et al (1999) report increased plant growth in potting-media enhanced with vermicompost derived from animal manures.

Recent research has demonstrated substantial yield increases when worm-worked wastes from grape-processing were used to supplement normal vineyard management (Buckerfield & Webster 1998). Similar studies can be used to test the use of organic-wastes from cotton processing to improve soil conditions for sustainable cotton-growth (Buckerfield 1998).

Substantial quantities of cotton-processing waste have been dumped and left to degrade in stockpiles around the gins. Cotton-producers who have recently recognized this as a potential source of organic matter to improve soil conditions, have trialled processing the wastes with worms; vermicompost, the finely-divided organic residue, is reputed to produce superior growth responses in plants Buckerfield & Webster (2000).

Working with cotton-growers, worm-growers have now developed the technology for worm-composting of cotton-processing wastes with feedlot-manures on a large scale. These primary producers needed to validate the economics of worm-worked wastes as a soil amendment for cotton-growing, and requested assistance from CSIRO Land & Water to develop field-trials to evaluate the performance of the organic materials for cotton production.

2. List the project objectives and the extent to which these have been achieved

To investigate the use of cotton-processing wastes as organic soil amendments for cotton production.

Establish field-trials with composted gin-trash to:

a. determine effects on cotton growth and yield.
b. assess effects on essential soil properties.

To conduct a field-assessment of organic-wastes as soil amendments in cotton production:

a. design and establish field-trials in collaboration with a commercial cotton producer.
b. apply prescribed rates of worm-composted organic-wastes prior to sowing.
c. monitor responses in cotton at critical stages of growth.
d. determine the cost-benefit of processing wastes for reuse on cotton soils.

The influence on cotton growth of a single application of the organic wastes has been determined at critical stages of development. Effects on cotton yields have been quantified over three successive seasons, indicating the longer-term and economic responses.

3. Detail the methodology and a justification for the methodology used.

Paddock-scale trials were established to evaluate the benefits of organic-wastes as soil amendments for cotton production. Soil treatments, with composted gin-trash from local cotton-processing and vermicompost from worm-worked feedlot-manure, were superimposed on the current cotton-growing practices.

The organic amendments were incorporated in the soil or spread on the surface of the beds; rates of 1, 2 or 5 m^3/ha vermicompost and 2 m^3/ha gin-trash or cattle-manure were considered commercially viable as a supplement to normal fertilizer applications.

To demonstrate applications of composted gin-trash, field trials were established with a commercial cotton grower at Moree, New South Wales. The organic soil amendments were applied during bed-preparation prior to planting, in the first year of cotton in a cereal/cotton rotation. Plant establishment and growth at flowering was correlated with the effects of the soil treatments on growth and yield at harvest.

The paddock was sown to cotton for a further two years; additional trials were established with increasing rates of the composted-wastes. Continued monitoring of growth and yield over three years determined the residual effect of a single application of the organic wastes on the growth of subsequent cotton crops.

	1997				1998				1999				2000		
1. Site visit, discussion with industry, trial design		■									■				
2 Trial Layout and Installation		■									■				
a. vermicompost and manure (Trial A)		■													
b. vermicompost and gin-trash (Trial B)											■				
3. Monitor responses at critical stages of growth				■				■					■		
4. Oversee collection & collation of harvest data						■				■				■	
5. Sample soils and compost for analysis		■						■		■			■	■	
6. Determine cost-benefit of composting							■				■				■
7. Reports to industry representatives							■	■				■			■

Experimental Design and Measurements

Site - A 60 ha paddock on the "Keytah" property 35km W of Moree, was selected as representative of the black-soils favoured for cotton-growing in the district. The paddock that had previously been sown to wheat could be monitored for at least two successive crops of irrigated summer cotton.

Layout

Trial A - An appropriate layout was determined to provide 2.4ha plots that could be harvested mechanically to provide complete module units for yield assessments. Each of the five vermicompost/manure treatment plots (600m x 40m) was replicated three times in a randomized block design.

Trial B – The layout was designed with 75m^2 plots (15m x 5m) to allow sampling of 10 metres of row in up to five adjacent rows. Each of the five vermicompost/gin-trash treatments was replicated five times in a randomized latin-square.

Treatments

Trial A - The vermicompost was produced from locally-available feedstock, comprising stockpiled feedlot-manure and cotton-trash residues from the gin. Composting worms (*Eisenia fetida*) were used to process the organic-waste mixtures in outdoor trenches; after four months the upper 10cm with worms was removed and the remainder used immediately on the trial plots. Local contractors assisted in calibration of fertilizer spreaders to enable effective distribution of the 'wet' vermicompost, dug directly from 'active' worm-beds.

Vermicompost treatments were selected at rates appropriate for comparison with animal manures which had commonly been used as soil amendments on the property; viz. 1, 2 & 5t/ha vermicompost and 2t/ha feedlot manure.

Trial B - The vermicompost was produced from piggery feedlot-manure with composting worms (*Eisenia fetida*) in raised mesh bins; after four months, the worm-worked material from the base of the beds was removed, screened and bagged. Cotton gin-trash residues had been stockpiled after harvest and allowed to compost in windrows for eighteen months.

Vermicompost treatments were selected at rates appropriate for comparison with soil amendments that had commonly been used on the property, viz. 1, 2 & 5m^3/ha vermicompost and 2m^3/ha gin-trash.

Rates and Spreading

Trial A – Discussion with growers determined that the most appropriate time for application of the treatments was immediately following hilling, but immediately prior to injection of anhydrous ammonia and final bed-preparation in April. This would ensure effective incorporation of the surface-applied organic materials, and adequate time for 'stabilization' prior to seeding with *Siokra V-15* cotton in October[1].

In April 1997 each of the treatments was broadcast at the prescribed rates with a truck-mounted rotary spreader, and incorporated immediately during bed-formation. Each of the treatments was superimposed on the normal-practice applications of fertilizer (control).

Trial B - It was agreed with growers that the most appropriate time for application of the treatments was after the hills had been prepared, and that the organic materials should remain concentrated on the surface, rather than incorporated as in previous trials.

With extended rains throughout August and September, it was not possible to apply the treatments until 2-3 days after seeding. In the first week of October 1998, each of the treatments was spread by hand at the prescribed rates and raked uniformly as a continuous band 20cm wide over the surface of the bed.

Sampling and Measurements

Discussion with growers and agronomists determined appropriate stages of plant development to indicate significant effects of the treatments on growth. Plants were sampled non-destructively along the mid-row, with measurements commencing 50 metres from the end-drain; additional samples were taken two rows either side of the mid-row of each plot. Adequate subsampling of treatment plots was undertaken to provide adequate data to verify the significant responses; statistical significance ($P<0.05$) was determined on individual plant measurements, using an ANOVA analysis (Statistix for Windows v2.0).

Flowering - Non-destructive measurements on plants were conducted in December 1997 and 1998 to demonstrate the influence of the treatments on establishment, flowering and fruit development. A cooler season slowed plant development and delayed measurements on the third crop until mid-February 2000.

Plant height was determined on ten adjacent plants from each of three rows in each plot; number of nodes, first-fruiting node, squares and fruits formed/retained and flowers-emerged were recorded for each plant.

Plant density was estimated from the number of plants in each of ten consecutive metre-lengths of row, repeated for a further ten metre-lengths five metres further into plot; three rows were sampled from each plot.

Year 1 - Sampling in mid-December 1997 also provided data on number of nodes and first-fruiting node; number of squares and fruits formed/retained and flowers-emerged were recorded for each of 1,200 plants.

Year 2 - A similar comprehensive sampling of 2,000 plants in mid-December 1998 demonstrated the influence of the treatments on establishment, flowering and fruit-development.

Year 3 – Measurements on plants in early-February 2000 provided additional data on boll numbers and plant spacing within a month of flowering; all bolls were counted, except those formed on the first four nodes below the youngest fully-open leaf.

Harvest - Cotton sown in October was harvested in the following April. Mature plant samples were collected within two days prior to the grower's machine harvest of the paddock. Measurements on

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[1] [a] Chisel-plough cultivation, vermicompost/manure and NH_3 application, hill preparation 15-17 April 1997. Cultivation, phosphate/zinc fertilizer application and bedshaping, 2-4 August 1997. Herbicide application, sowing with 'Siokra V-15' cotton, 1 October 1997. First full irrigation 2 December 1997.

sufficient replicate samples ensured sufficient data to determine statistical significance of the treatments.

Year 1 – Cotton yields were estimated on module-weights from 2.4ha treatment plots and quadrat samples from 4 x 10m of row from each plot, with three replicate plots of each treatment (Trial A). Plant density and individual plant weights, height, boll number and weights, rejects and lint-recovery were recorded on over 4,000 mature plants.

Year 2 – Harvest sampling was repeated on the vermicompost/manure trial set up 18 months previously (Trial A) and the adjacent vermicompost/gin-trash trial established 6 months prior to sampling (Trial B).

Trial A - Increases in cotton growth and yields, related to the vermicompost treatments, were recorded from quadrat samples on each of the trial plots and from module-weights on 2.4ha plots.

Trial B - Cotton yields in April 1999 were estimated from quadrat sampling with 4 x 5-plant samples from the middle row of each three-row plot, with five replicate plots of each treatment. Plant density, plant heights, boll number and weights of individual plants, were recorded on over 1,000 mature plants.

Year 3 - These plots were monitored again at flowering and harvest, with quadrat samples to determine plant density, flower and fruit development, boll numbers and weights. At harvest, three 5-plant samples were collected each plot, a total of 75 plants from each treatment.

Soil Sampling - Soils were sampled comprehensively from each of the plots in December 1998, April 1999 and April 2000. Air-dried and ground subsamples (<2mm) were submitted to the Primary Industries and Resources (SA) Soil and Plant Analysis Service for accredited testing.

4. Detail results including the statistical analysis of results

Data is presented to illustrate the effects of the organic soil amendments on cotton growth, for up to three successive seasons. A selection of graphs indicates significant responses in each of the growth and yield parameters and soil factors measured on each of the trials (Attachment B).

Year 1 - *Cotton sown in October 1997 was measured in December, during the early stages of flowering. There were no obvious effects of the vermicompost and manure treatments on plant height, within the first two months of growth. But there were significant effects on plant establishment, flowering and fruit development.*

There were indications that the highest rate of vermicompost may have reduced germination and establishment; but this treatment was also associated with a significant increase in internode length, and earlier development of the first fruiting-node. The lower rates of vermicompost were associated with an increase in plant density, indicating better plant establishment.

These differences were reflected in significant cotton yield differences in the following harvest in April 1998. Quadrats harvested showed yields were up to 15% higher with the higher rates of vermicompost incorporated in the soil prior to seeding; similar yield increases were demonstrated with module-weights and lint yields from the gin. The manure had no significant effect on cotton yields.

Flowering – The measurements in December, after two months of plant growth, give clear indications of responses related to the vermicompost and manure treatments, incorporated before seeding (Trial A).

Plant Density - There were significant differences in plant density, with number of plants ranging from 5.4 to 6.9 per metre of row (Fig. 1.1). The lower rates of vermicompost (1, 2t/ha) were associated with a significant increase in plant density; the manure had no effect. There were indications that the highest rate of vermicompost may have reduced germination and establishment, but this may be compensated for with less inter-plant competition during later growth.

Plant Heights averaged 47.5±0.5 cm, and were greatest with the highest rate of vermicompost (Fig. 1.2). Plant height was significantly correlated with higher number of both nodes and fruits ($r=0.58$ and $r=0.64$, $P<0.0001$). There was an inverse relationship between plant height and plant density ($P<0.001$).

Internode Length - Significant differences in the number of nodes and average internode length may indicate differences in soil-moisture under the different rates of vermicompost and manure. Up to 18 fruiting-nodes per plant were recorded at the time of sampling; this averaged 13.0±0.1 overall, with fewest nodes associated with the highest rate of vermicompost (Fig. 1.3). There were also clear differences in average internode length (Fig. 1.4); with fewer nodes and an increase in plant height, there was significantly greater internode length on plants with the higher vermicompost treatment ($P<0.001$).

An inverse relationship between plant density and internode length ($P<0.01$) could indicate contrasts in moisture stress; this could be confirmed with occasional measurements during the growing-season, to be correlated with soil-moisture under the different rates of vermicompost.

Fruit and Flower Development - The higher rates of vermicompost (2 & 5 t/ha) were associated with first fruit development on nodes significantly lower on the plant than the control (Fig. 1.5). This provides potential for more fruits to develop; this is evident with an increase in the number of fruits developing with higher rates of vermicompost (Fig. 1.6). There is evidence of fewer flowers having emerged with the high vermicompost and the manure treatments, at the time of sampling (Fig. 1.7).

Harvest – the measurements on mature plants in April indicate responses of cotton to the vermicompost and manure, twelve months after the treatments were incorporated in the soil.

Plant Density - As noted at flowering, there was an apparent increase in plant density with each of the organic soil amendments (Fig. 1.8); this was not related to rates of organic matter, and there was an indication that plant density was lower with the highest rate of vermicompost (c.f. Fig. 1.1). There is a clear correlation between plant density recorded at flowering and later, on the same plants at harvest; this suggests that although there was a slight reduction in plant density between December and April there was no mortality related to the organic matter treatments.

Yields – The total weight of bolls harvested increased with increasing rate of vermicompost; the manure treatment had no effect on boll weights (Fig. 1.9). The weight of cotton recovered with 1t/ha vermicompost was 15% higher than the untreated control (Fig. 1.10). However the weight of cotton decreased with the higher rates of vermicompost, suggesting that the higher vermicompost may have increased vegetative growth but not the weight of fibre; this was confirmed with cotton yield expressed as % of the total boll weight (Fig. 1.11).

When lint recovery from the gin was taken into account, there was an apparent increase in yield of up to 2.5% with increasing vermicompost (Fig. 1.12) although yields estimated from quadrats were not significant ($P<0.05$).

Module weights from harvest of each of the 2.4ha plots indicate an increase in raw cotton yields, related to the vermicompost (Fig. 1.13); weight of cotton with 5t/ha vermicompost was 5% higher than the untreated control.

Year 2 – *Cotton sown in October 1998 was measured in December, during the early stages of flowering. There were obvious effects on plant-density and plant height, and it was clear that the vermicompost and gin-trash treatments had influenced plant establishment, flowering and fruit development during the first two months of growth.*

Each of the organic matter treatments reduced plant density; it appears that the vermicompost and the composted gin-trash had reduced cotton germination and establishment. But the highest rate of vermicompost and the gin-trash were also associated with a significant increase in both plant height and number of nodes and with the first fruiting-node developing higher on the plant.

At harvest in April 1999, the higher rates of vermicompost and gin-trash produced increased numbers and weight of bolls per plant; but with these treatments spread on the surface after seeding, a reduction in plant density resulted in cotton yields reduced by up to 5% compared with the normal-practice control.

After a second year, the larger-scale plots with the composted organic wastes incorporated into the soil prior to seeding, continued to show yield responses with weights of raw cotton up to 25% higher; but lint yields were apparently reduced with the higher rates of vermicompost and manure. Once again, there is evidence of an increase in the vegetative growth of cotton, but not in cotton yields.

Flowering - The measurements in December 1998, give clear indications of responses related to the vermicompost and gin-trash treatments (Trial B). The surface applications after seeding had apparently affected germination and plant establishment; plant density was significantly reduced with each of the organic amendments (Fig. 2.1). There were obvious differences in plant height, within the first two months of growth with the higher rates of vermicompost; plant growth and number of nodes increased significantly with the gin-trash (Figs 2.2 & 2.3).

Increase in plant height was correlated closely with increase in number of nodes; there was no significant difference in average internode length related to the organic-matter treatments (Fig. 2.4), but the first fruiting-node was higher on the plant with the high vermicompost and gin-trash treatments (Fig. 2.5). The vermicompost and gin-trash treatments appear to have increased number of fruits developing on plants at early flowering stage (Fig. 2.6).

Harvest – As noted at flowering (Fig. 2.1), plant density at harvest was reduced with increasing rates of vermicompost and with the gin-trash (Fig. 2.7). The composted gin-trash and the higher rates of vermicompost significantly increased boll numbers and boll weights per plant; increases with the highest vermicompost rate and the gin-trash compost were up to 20% higher (Figs 2.8 & 2.9). However, overall yields were not increased with the organic soil amendments; with the reduction in plant density cotton yield was reduced, with the high rate of vermicompost 5% lower than the untreated control (Fig. 2.10).

The larger-scale plots (Trial A), with the composted organic wastes incorporated into the soil prior to seeding, were harvested after a second year of cotton. Extended rains resulted in water-logging and plant-damage to plots in Block 1, reducing the replicates available for statistical analysis. Although differences between treatments were not statistically significant, there is an indication of yield responses (Fig. 2.11); weight of raw cotton (harvested with quadrat-sampling in Block 3) was up to 25% higher with the higher rates of vermicompost and manure. Mechanical harvesting and ginning (modules from each of the five treatments in Block 2) produced between 21 and 23 bales per 2.4ha plot; weight of lint recovered (Fig. 2.12) indicated a reduction in fibre yield with the higher rates of vermicompost and with the manure.

Year 3 – *No additional organic amendments were applied to the trial plots in 1999. Measurements were conducted on plants sown in October 1999 to assess the residual effects of vermicompost/manure incorporated in the soil in April 1997 (Trial A) and vermicompost/gin-trash spread on the surface in October 1998 (Trial B).*

Plant height and plant density were reduced by each of the vermicompost treatments as well as the manure and gin-trash. Plant responses to the two vermicomposts differed; with cattle-manure vermicompost incorporated in the soil prior to seeding, boll numbers per plant were reduced, but increased with the pig-manure vermicompost spread on the surface after seeding.

The weight of cotton produced per plant increased but, with lower plant density, cotton yields were significantly reduced. The effects of the vermicompost, gin-trash and manure on cotton establishment were still evident for up to three years; the continuing influence on growth and yields suggests that the composted organic wastes have a significant effect on soil properties.

'Flowering' – Extended periods of cooler weather delayed flowering and the assessments of early growth were left until February, when counts of boll numbers provided an indication of responses to the organic soil amendments.

Trial A – There was no significant effect of the treatments on plant establishment ($P<0.05$), but there are indications of a reduction in plant density with the lower rates of vermicompost and an increase with the manure (Fig. 3.1). Plant heights and number of bolls per plant were reduced with the vermicompost (Figs. 3.2 & 3.3). Combined with reduced plant density with the vermicompost, this resulted in a reduction of up to 30% in the number of bolls per metre of row (Fig. 3.4); there was a small but insignificant reduction in boll density on the plots that had been treated with manure. (30 months previously.)

Trial B – As in the previous year, plant establishment was significantly affected on plots where organic matter had been added; plant density reduced by increasing rates of vermicompost, and with the gin-trash, by up to 30% (Fig. 3.5). Plant height was significantly reduced with the highest rate of vermicompost (Fig. 3.6). Boll numbers per plant increased significantly with vermicompost (Fig. 3.7) but because of effect of the vermicompost in reducing plant density, only the lowest rate of vermicompost produced a higher boll density (Fig. 3.8).

Harvest – Quadrat samples of mature plants were removed for a comprehensive assessment of growth and yield parameters, immediately before the grower's harvest.

Trial B – Plant density was significantly reduced by each of the organic soil amendments, with an apparent dose response to increasing rates of vermicompost (Fig. 3.9). A similar effect was reported when these plants were measured two months previously (c.f. Fig. 3.5); correlations indicate that there had not been any significant mortality on these plots late in the season. There are indications that plant height at maturity (Fig 3.10) was significantly reduced by the vermicompost treatments ($P<0.05$), but this was not related to the rates of vermicompost that had been applied (Fig. 3.10).

As in the previous year (c.f. Fig. 2.8), boll numbers per plant increased significantly with each of the organic soil amendments (Fig. 3.11). But once again, with the effect of the vermicompost and gin-trash on plant density, boll density was significantly reduced (Fig. 3.12). Number of bolls per metre of row were 25% lower with the highest rate of vermicompost; the effect of the composted gin-trash was similar to the comparable rate of vermicompost.

Once again, the weight of cotton recovered per plant was higher with the vermicompost and gin-trash (c.f. Figs 2.9 & 3.13). But with the reduction in plant density (Fig. 3.9), cotton yields were reduced by up to 25% ($P<0.05$) with the highest rate of vermicompost and the gin-trash treatments (Fig. 3.14).

Soil Analyses

The effects of the vermicompost and gin-trash on germination were not obviously related to the small influence on pH, but may be associated with a considerable increase in electrical conductivity. Soil nutrients were not clearly associated with subsequent growth and development. There were higher levels of nitrogen and phosphorus with the vermicompost, but not with the gin-trash; the gin-trash contributed to substantial increases in levels of soil potassium. Levels of sulphur in the soil increased significantly and each of the organic amendments substantially increased soil organic carbon. Further studies may indicate the importance of soil biological factors in determining the effects of organic amendments on cotton growth and yields.

Analyses of soils, within two and six months of the treatments being applied, indicated significant differences in properties that could influence cotton establishment and growth (Table 1b). The effects of the gin-trash and vermicompost on soils are summarized in Figs 4.1 - 4.12.

Soil pH - With vermicompost, there was a tendency to lower pH; with the higher rates of vermicompost, soil pH was reduced by up to 0.4 of a unit (Figs 4.1, 4.2).

Electrical Conductivity – With the higher rate of vermicompost, electrical conductivity increased significantly ($P<0.05$); electrical conductivity also increased with the gin-trasb (Figs 4.3, 4.4).

Ammonium-Nitrogen – There was an indication of increased levels of ammonium-nitrogen with the lower rate of vermicompost, but a reduction with the higher rates of vermicompost and the gin-trash (Fig. 4.5). The availability of ammonium-nitrogen associated with organic residues can be expected to change as the organic residues degrade in the soil.

Nitrate- Nitrogen - Increasing levels of nitrate-nitrogen were related to increasing rates of vermicompost, with the highest rate almost double the control ($P<0.05$). The gin-trash did not significantly increase nitrate-nitrogen levels in the soil (Fig. 4.6). The effects of the vermicompost on the availability of soluble nitrogen could have a significant influence on plant growth.

Phosphorus - There was a trend towards increasing phosphorus levels with increasing rates of vermicompost; the highest rate of vermicompost was significantly higher than the control. The soil phosphorus levels did not increase with the composted gin-trash (Fig. 4.7).

Potassium - Vermicompost tended to increase soil potassium, with the higher rates having levels significantly higher than the control ($P<0.05$). The composted gin-trash significantly increased potassium, by almost 50% (Fig. 4.8).

Sulphur - With the higher rate of vermicompost and with the composted gin-trash (Fig. 4.9), levels of soil sulphur increased significantly ($P<0.05$); this may have contributed to higher pH with these treatments, and may have influenced availability of nutrients.

Organic Carbon – Each of the treatments increased the levels of soil organic carbon (Fig. 4.10); the effect of the composted gin-trash was similar to the similar rate of vermicompost. With the highest rate of vermicompost, soil carbon almost doubled ($P<0.05$); this may be a major factor modifying soils for cotton growth.

Analyses of vermicompost and gin-trash were determined by the methods used for the accompanying soils; methods of extraction for organic materials may produce differing results (e.g. pH & E.C. on 1:5 solution and 1:1.5 pour-through extract (Handreck & Black 1994)). With the gin-trash, the high pH and electrical conductivity could be expected to influence germination and seedling development (Table 1a).

The detrimental effects of the vermicompost on cotton establishment may be related to salinity, associated with high electrical conductivity (Table 1b); problems are likely to be more severe, with an increase of sodium uptake in waterlogged soils (Handreck & Black 1994). The influence of soil chemical factors associated with flood-irrigation may be important in the growth of young cotton plants; leaching and the loss of available nitrogen, and the high levels of sulphur linked with waterlogging, should be considered more fully.

High levels of organic matter will provide a substrate for increased biological activity and can be expected to affect soil physical characteristics, influencing water-holding and drainage. Poor aeration may increase susceptibility of the plant to pathogens; anaerobic soil conditions may reduce the effectiveness of beneficial microorganisms associated with plant roots.

Additional studies, which could now be conducted in the glasshouse, are needed to confirm whether the effects on germination and growth were due to physical or chemical properties or with biological factors associated with the organic amendments.

5. Discuss the results, and include an analysis of research outcomes compared with objectives.

This three-year research project was established initially with commercial growers as a single-season scoping study, to determine the benefits of utilizing worm-worked wastes from the cotton industry as amendments to improve soils for cotton production. Other organic residues such as cattle manures available in the region were used for comparison of the effects on cotton growth and yields.

A broadcast application of worm-composted manure and gin-trash, applied during early bed-preparation, had a significant influence on the subsequent crop. There were clear indications of a dose-response, with a reduction in plant establishment, but higher yields associated with higher rates of vermicompost. There was also evidence of added benefits of worm-processing, with no increases in the growth and yield of cotton treated with comparable rates of manure.

We had satisfied the initial objectives of the project - to demonstrate benefits and economic rates for application of worm-worked wastes to assist in sustainable cotton production. Increases of up to 15% in lint yields would have provided adequate additional return in the first year to justify applications with the higher rate of vermicompost produced from locally-available organic wastes.

The paddock with the trial-plots was to be sown to cotton for a second year, providing opportunities to continue monitoring of the longer-term effects of a single application of organic matter and to extend the study to other organic wastes, including an assessment of composted gin-trash.

The higher rates of vermicompost and the gin-trash had significantly increased plant height and the number of nodes developing at flowering. But an increase in boll numbers and cotton yields developing on each plant were not sufficient to compensate for a substantial reduction in plant density. In this season, when the vermicompost and gin-trash was applied at seeding, yields associated with the organic amendments were up to 5% lower than with cotton harvested on adjacent untreated plots.

With cotton sown on the trial plots for a third year, we had opportunity to determine whether the unexpected reduction in yields had been due to seasonal factors. Comparisons between the two trials could also confirm whether the differences in timing or methods of application were important in influencing growth and yields.

Once again, each of the vermicompost, manure and gin-trash treatments had an influence on cotton establishment, with the higher rates significantly reducing plant density at flowering. These differences persisted through to harvest and, although the organic amendments increased plant height and boll numbers, overall yields were significantly reduced. There are clear indications that, had the grower applied the composted gin-trash treatments more widely, yields in this season could have been reduced by up to 25% on the trial paddock.

The reductions in cotton growth and yields had not been anticipated, and the objectives of the project were redefined over three years. There is a wide perception that organic wastes, if processed to destroy plant pathogens, provide a 'safe' source of carbon to improve soils for sustainable cotton production. While the composted amendments provided supplementary organic matter for deficient soils, there is now a need to confirm that the changes in soil properties are not, at the same time, compromising plant growth.

Composted organic wastes from three separate sources, viz. cattle-manure, pig-manure and cotton gin-trash, all increased plant growth, but reduced plant density. This resulted in significant reductions in cotton yields, related to the higher rates of organic matter. These differences persisted for up to three successive years of cotton, irrespective of the timing or methods of application of the organic amendments.

Our research complements a study with vermicompost from the same source, at similar rates, conducted at Narrabri on irrigated cotton at the Australian Cotton Research Institute. The study by Rochester and Constable (1998) reports an increase in plant establishment but a decrease in cotton yields with increasing rates of vermicompost. The vermicompost did not increase crop nutrient uptake; this indicated that the reduced yields were not related to plant nutrition, but may be related to biological factors. Studies by Hulugalle (1996) will provide indications of the effects of organic amendments of organic amendments on the essential properties of soils used for cotton-growing.

6. Provide an assessment of the likely impact of results and conclusions of the research project for the cotton industry. Include a statement of the costs and potential benefits to the Australian cotton industry and future research needs.

Impact on the Industry - We have clearly demonstrated significant reductions in cotton yields, related to the higher rates of supplementary organic matter. These differences have persisted for up to three successive years of cotton, irrespective of the timing or methods of application of the organic amendments.

The importance of soil organic matter for the maintenance of soil structure, and the efficient use of water and nutrients is now widely recognized; low soil organic carbon has been identified as a significant limiting factor in agricultural production. In current industry-funded studies there is an assumption that retaining crop residues and supplementing with other organic wastes will benefit soils for sustainable cotton production. Our research indicates that it cannot be assumed that organic matter will improve cotton growth.

When applied on a larger-scale by cotton-growers, the effects of organic materials, which may be reducing yields by up to 25%, are unlikely to be attributed to composted organic matter which has been considered a 'safe' supplement. Before committing to broadacre use of composts, manures and crop-residues, growers should consider small-scale trials to determine the growth-responses on the soils to be sown with cotton.

Additional Research – The mechanisms causing yield reductions now need to be identified; principles developed for safe use of supplementary organic matter will be of wider relevance in management of crop residues and for efficient use of water and nutrients. This can extend studies by Gemtos and Lellis (1997) which showed interactions between soil properties, water and organic matter on cotton development.

Within the cotton industry, there is now a need to determine whether the 'problems' we have identified apply to the range of soils used for cotton-growing. The importance of aerobic conditions for developing seedlings may be critical for establishment and growth of cotton. Occasional water-logging in heavier soils, with influences on nutrient availability and soil biology may affect plant response to organic matter in the soil. There is also a need to clarify, with research, whether the effects of organic matter on growth apply equally to flood-irrigated and dry-grown cotton.

The negative effects of the added organic matter on cotton establishment and growth complement our studies, with similar conclusions, on other crops as diverse as carrots, radishes and cereals. We are presently designing glasshouse-bioassays which will predict the effect of organic amendments on specific soils; these will be relevant to a range of crops and could be developed with assistance from several horticultural industries.

The involvement of grower-groups in future research could assist in developing recommendations for appropriate processing and applications for organic materials on cotton soils.

7. Describe the project technology (e.g. commercially significant developments, patents applied for or granted, licenses, etc).

The project has not developed commercial property, but has indicated that accepted grower-practices may be promoting significant yield losses. A test which identifies unsuitable combinations of soils and organic matter has commercial potential; the simple bioassay which could be developed as an extension to our research could be licensed.

8. Provide technical summary of other information developed as a part of the research project. Include discoveries in methodology, equipment design, etc.

The significant effects of the organic amendments on germination indicate a critical influence on soil properties. While an increase in plant growth suggests increased nutrient availability, this was not sufficient to compensate for detrimental effects on cotton establishment. The research project has identified conditions in which supplementary organic matter has reduced cotton yields.

With organic matter from three distinct sources, the effects of a single application persisted through successive cotton crops. There is sufficient evidence, with consistent responses for up to three years, for cotton-growers to consider a bioassay to determine the effects of organic amendments on their soils prior to planting.

This project has assisted in developing field-methodology for determining responses to alternative management strategies for cotton. We have applied principles of population biology to trial-design and plant-sampling, and have ascertained levels of variability and sample size to provide a statistical assessment of key plant-growth parameters.

9. State the recommendations on the activities or other steps that may be taken to further develop, disseminate, or to exploit the project technology.

We should be conservative in providing recommendations to the industry at this stage. While there is ample evidence to promote caution in the use of supplementary organic matter on cotton soils, we need to confirm that our results are relevant to a wider range of soils and management practices.

Re-use of cotton-processing wastes is not currently a common practice, due to potential risks for spreading pathogens. We support the industry concern for the risk of pathogens with imported plant residues and encourage caution in the use of organic wastes which could carry cotton disease. The composted materials derived from animal manures, are not likely to pose a risk of plant disease.

But we consider it important that growers are now made aware that there is evidence of yield reductions, with a variety of organic amendments. Data from successive crops with different cotton varieties, confirms that the effects of a single application can persist in its effects on germination and growth.

We appreciate the sensitivity in promoting our findings more widely at this stage, and will be guided by CRDC on appropriate methods to disseminate the results to the industry.

10. List the publications arising from the research project.

Poster papers have been presented, for discussion at relevant conferences. We will be pleased to discuss appropriate journals for publication with colleagues.

Buckerfield, J.C. (1998). Worm-worked waste as an organic amendment for cotton soils. *The Ninth Australian Cotton Conference*, 12-14 August 1998. Queensland, Australia. pp. 767-772.

Buckerfield, J.C. and Webster, K. A. (in press). Evaluation of worm-worked wastes with field-trials. In: "Merging the Best from Science and Industry". *Vermillenium - International Conference on Vermiculture and Vermicomposting*, Kalamazoo MI. September 2000.

Johnson, P. (1998). Cotton looks seriously at worms. Moree vermicast trials compare fertiliser values. *The Land*, Jan. 1 1998, p.27.

Acknowledgements

The project was initiated by Mr David Statham of the Sundown Pastoral Company; we have appreciated the ongoing support of his staff, in particular Mr Andrew Parkes, Agronomist, 'Keytah' Moree. Vermicompost production and spreading for Trial A was supervised by Mr Tony Hayes. Vermicompost for Trial B was supplied by Vermitech Pty Ltd, through Mr Thomas Williams; considerable field assistance and support has been provided by Dr Rob Blakemore. We gratefully acknowledge the continued funding from the Cotton Research and Development Corporation to establish and monitor these trials.

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Buckerfield, J.C. and Webster, K.A. (1998). Worm-worked waste boosts grape yields - prospects for vermicompost use in vineyards. *The Australian and New Zealand Wine Industry Journal* 13(1): 73-76.

Buckerfield, J.C. and Webster, K.A. (2000). Vermicompost – more than a mulch. Vineyard trials to evaluate worm-worked wastes. *The Australian Grapegrower and Winemaker*, 28th Annual Technical Issue 2000, No. 438a, pp. 160-166.

Buckerfield, J.C., Flavel. T.M., Lee, K.E. and Webster, K. A. (1999). Vermicompost applications in solid and liquid form as a plant-growth promoter. *Pedobiologia* 43: 753-759.

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Handreck, K.A. and Black, N.D. (1994). Growing Media for Ornamental Plants and Turf. UNSW Press, Sydney.

Hulugalle, N.R. (1996). Effects of palletized sewage sludge on soil properties of a cracking clay from Eastern Australia. *Waste Management and Research* 14(6): 571-580.

Johnson, P. (1998). Cotton looks seriously at worms. Moree vermicast trials compare fertiliser values. *The Land*, January 1 1998, p.27.

Rochester, Ian and Constable, Greg (1998). Evaluation of Vermicast in irrigated cotton production. Research Report CSIRO, Narrabri, New South Wales.

	Vermicompost	Composted Gin-Trash
pH (1:5 water)	6.9	8.2
pH ($CaCl_2$)	6.6	7.9
Electrical Conductivity - EC (1:5)	1.75	9.7
Electrical Conductivity - EC_e (est)	16.6	92.1
NH_4^+ - N (mg/kg)	12	21
NO_3^- - N (mg/kg)	31	100
P (mg/kg)	805	771
K (mg/kg)	1248	2993
S (mg/kg)	494	2519
Org C (%)	5.59	6.11

Table 1a – Analysis of vermicompost and composted gin-trash used in field-trials spread on surface at seeding (Trial B, October 1998).

1998	Control	Vermicompost 1m³/ha	Vermicompost 2m³/ha	Vermicompost 5m³/ha	Gin-Trash Compost 2m³/ha
pH (water)	8.65 (0.05)	8.25 (0.15)	8.2 (0.3)	8.25 (0.15)	8.20 (0.20)
pH ($CaCl_2$)	7.80 (0)	7.55 (0.15)	7.60 (0.20)	7.60 (0.10)	7.60 (0.20)
EC (1:5)	0.195 (0.015)	0.215 (0.025)	0.215 (0.035)	0.295 (0.005)	0.295 (0.075)
EC_e (est)	1.25 (0.15)	1.35 (0.15)	1.4 (0.2)	1.9 (0)	1.9 (0.5)
NH_4^+ - N (mg/kg)	9.0 (2.0)	9.5 (1.5)	8.5 (1.5)	8.5 (2.5)	8.5 (1.5)
NO_3- - N (mg/kg)	17.0 (4.0)	20.5 (1.5)	31.0 (14.0)	52.5 (3.5)	33.0 (12.0)
P (mg/kg)	103 (4)	239 (30)	118 (7)	260 (71)	148 (41)
K (mg/kg)	457 (7)	514 (64)	642 (10)	507 (19)	726 (12)
S (mg/kg)	17.3 (8.4)	29.3 (7.7)	23.6 (8.3)	50.5 (5.5)	65.5 (28.7)
Org C (%)	0.66 (0.01)	0.83 (0.11)	0.90 (0.04)	0.77 (0.04)	0.88 (0.08)

1999	Control	Vermicompost 1m³/ha	Vermicompost 2m³/ha	Vermicompost 5m³/ha	Gin-Trash Compost 2m³/ha
pH (water)	8.35 (0.25)	8.45 (0.05)	8.30 (0.30)	8.20 (0.30)	8.4 (0)
pH ($CaCl_2$)	7.55 (0.15)	7.65 (0.05)	7.55 (0.30)	7.60 (0.30)	7.80 (0.10)
EC (1:5)	0.22 (0.02)	0.20 (0.01)	0.26 (0.06)	0.31 (0.03)	0.25 (0.10)
EC_e (est)	1.45 (0.15)	1.30 (0.10)	1.70 (0.40)	2.00 (0.20)	1.65 (0.65)
NH_4^+ - N (mg/kg)	11 (2)	8 (2)	7 (1)	9 (3)	9 (2)
NO_3- - N (mg/kg)	10 (3)	18 (3)	16 (3)	26 (3)	19 (5)
P (mg/kg)	317 (213)	265.5 (30)	194 (62)	344 (233)	138 (11)
K (mg/kg)	507 (11)	540 (46)	824 (259)	641 (77)	604 (99)
S (mg/kg)	48.1 (33.0)	30.0 (3.9)	46.6 (21.1)	87.8 (29.1)	60.0 (41.0)
Org C (%)	1.34 (0.57)	1.10 (0.09)	0.94 (0.09)	1.74 (0.47)	1.16 (0.16)

Table 1b – Soil Analyses - mean (± S.E.) - from vermicompost/gin-trash trial (Trial B), April 1998, 1999 – Moree, NSW.

Plain English Summary

Research Project SPC1C - Final Report

Composted organic wastes as soil amendments for sustainable cotton production.

Many of the soils used for cotton-growing are now considered deficient in the organic-matter needed for maintenance of soil structure and efficient use of water and nutrients. While conserving crop-residues has shown benefits, growers have recognized the need for supplementary organic-matter to maintain levels required to sustain cotton production on these soils.

Until recently, substantial quantities of organic wastes from cotton-processing have been dumped and left to degrade in stockpiles around the gins. This gin-trash has been identified as a potential source of the organic-matter needed to improve soil conditions. Local growers have trialled composting the cotton-wastes and also vermicomposting, through additional processing with worms, to produce finely-divided organic residues. While these materials are reputed to produce superior growth responses in plants, there have been no adequate guidelines on appropriate applications compatible with commercial cotton management.

To evaluate the benefits of organic-wastes as soil amendments for cotton production, trials were established in cooperation with commercial growers. Soil treatments with composted gin-trash from local cotton-processing and vermicompost from worm-worked cattle-feedlot or pig-manure, were superimposed on the current growing practices. The organic amendments were incorporated in the soil or spread on the surface of the beds at rates considered commercially viable as a supplement to normal fertilizer applications.

Effects on establishment, growth, flowering and fruit development were determined on some 4,000 plants. A similar number of plants were harvested, and yield and vegetative components assessed. Module weights were recorded for each treatment, and lint and bale yields determined after ginning.

In the first season, vermicompost incorporated in the soil during seed-bed preparation increased cotton yields by up to 15%; manure at comparable rates had no effect on the growth or development of cotton. The organic amendments showed continuing growth responses in the second year, with an increase in the vegetative growth; weights of raw cotton were up to 20% higher. But plant density was lower, and lint yields were actually reduced with higher rates of vermicompost and manure.

When the vermicompost and gin-trash was applied at seeding, there was a clear response in plant growth. The higher rates of vermicompost and the gin-trash significantly increased plant height and the number of nodes developing at flowering. But yields associated with the organic amendments were lower than with cotton harvested on adjacent untreated plots. The increase in boll numbers and weights at harvest were not sufficient to compensate for a substantial reduction in plant density; cotton yields were at least 5% lower.

In the following year, measurements indicated that plants treated with the compost amendments were larger and had more bolls developing after flowering. But increased plant spacing suggested that the extra organic-matter had adversely affected germination and establishment. The harvest confirmed substantially improved plant growth, with larger plants and increased boll number and weights with the compost. But with the reduced plant density, overall yields were reduced by 25% with the supplementary organic-matter.

Composted organic wastes from three separate sources, viz. cattle-manure, pig-manure and cotton gin-trash, all increased plant growth, but significantly reduced germination and plant density. This resulted in significant reductions in cotton yields, related to the higher rates of organic-matter. These differences persisted for up to three successive years of cotton, irrespective of the timing or methods of application of the organic amendments.

The effects on cotton establishment are unlikely to be attributed to composted organic-matter which has been considered a 'safe' soil supplement. Before committing to broadacre use of composts, manures and crop-residues, growers should consider small-scale trials to determine the growth-responses on the soils to be sown with cotton.

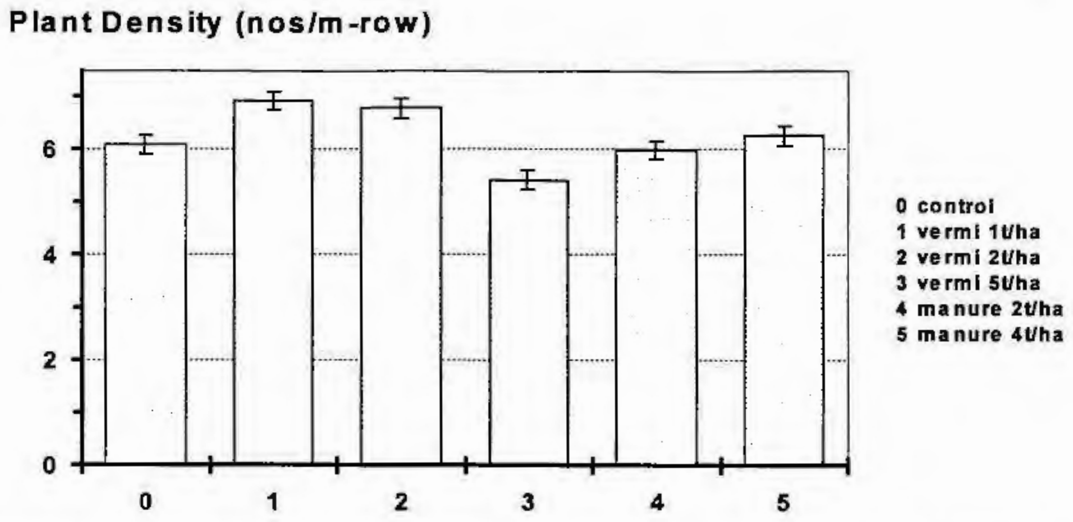

Fig. 1.1 - Establishment of cotton, with vermicompost/manure – Trial A - 16/12/97.

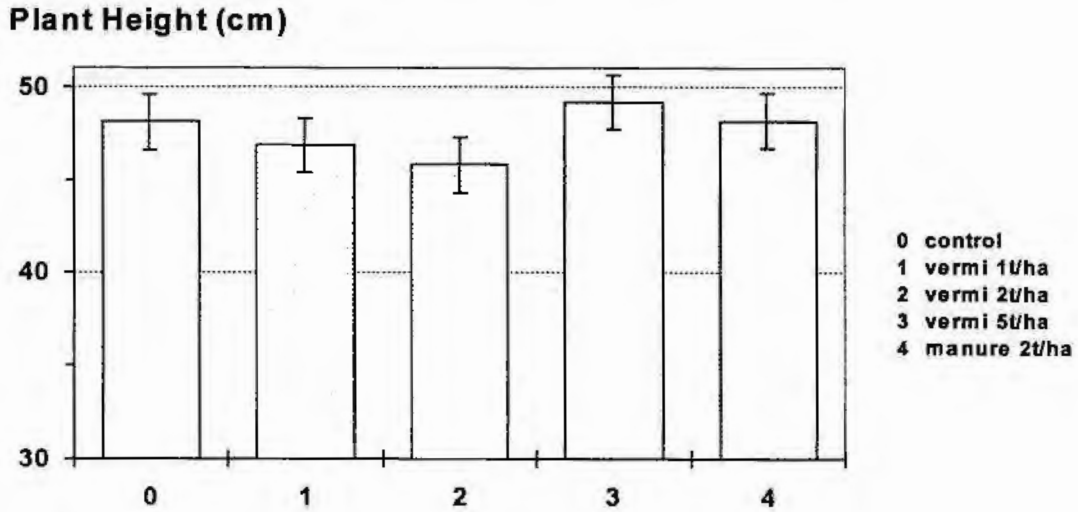

Fig. 1.2 - Plant height of cotton with vermicompost/manure – Trial A - 16/12/97.

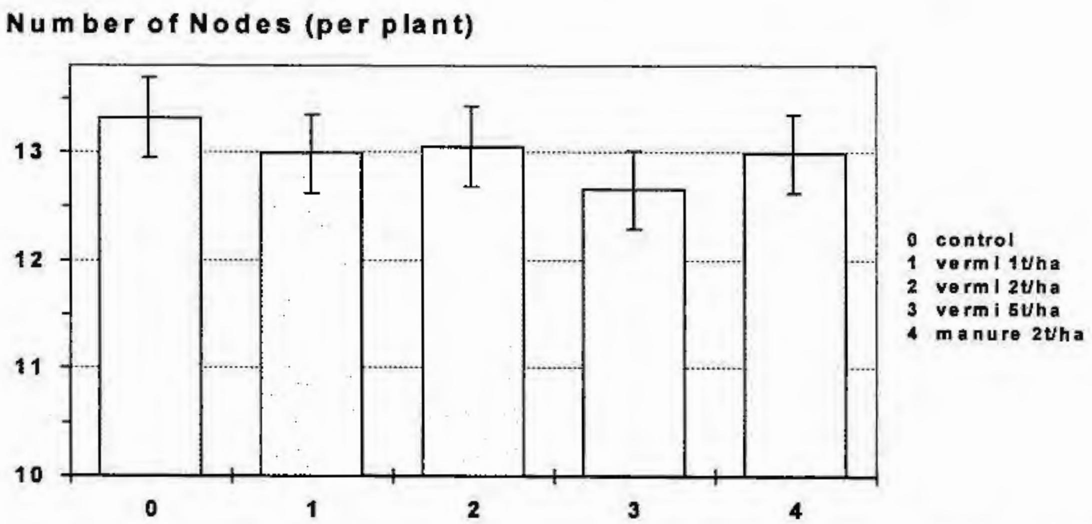

Fig. 1.3 - Number of nodes/plant, cotton with vermicompost/manure – Trial A - 16/12/97.

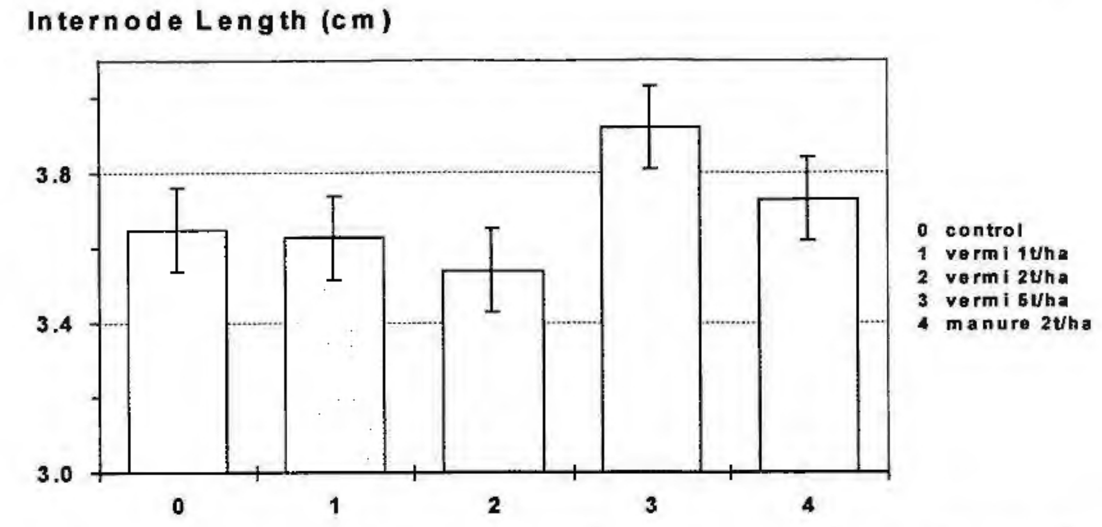

Fig. 1.4 - Average internode length, cotton with vermicompost/manure – Trial A - 16/12/97.

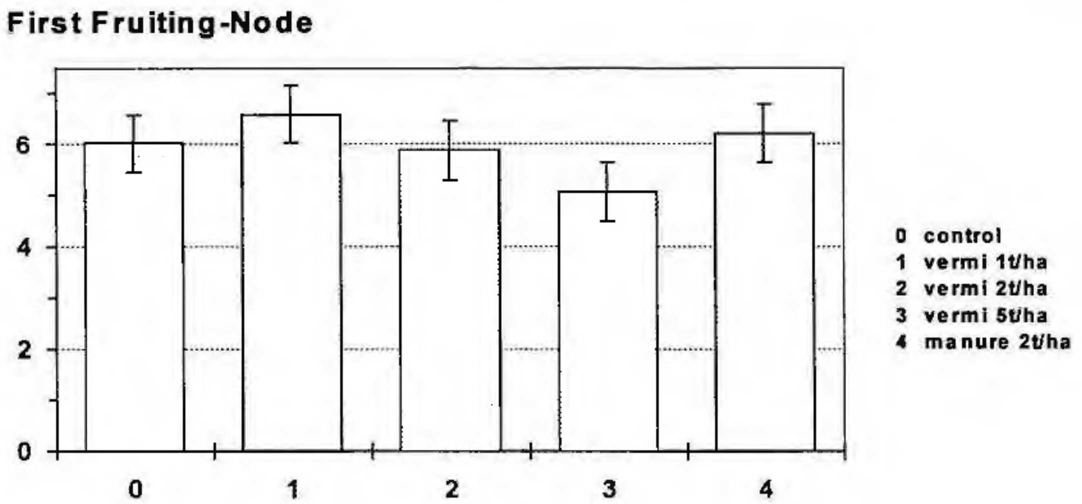

Fig. 1.5 - First fruiting node, cotton with vermicompost/manure – Trial A - 16/12/97.

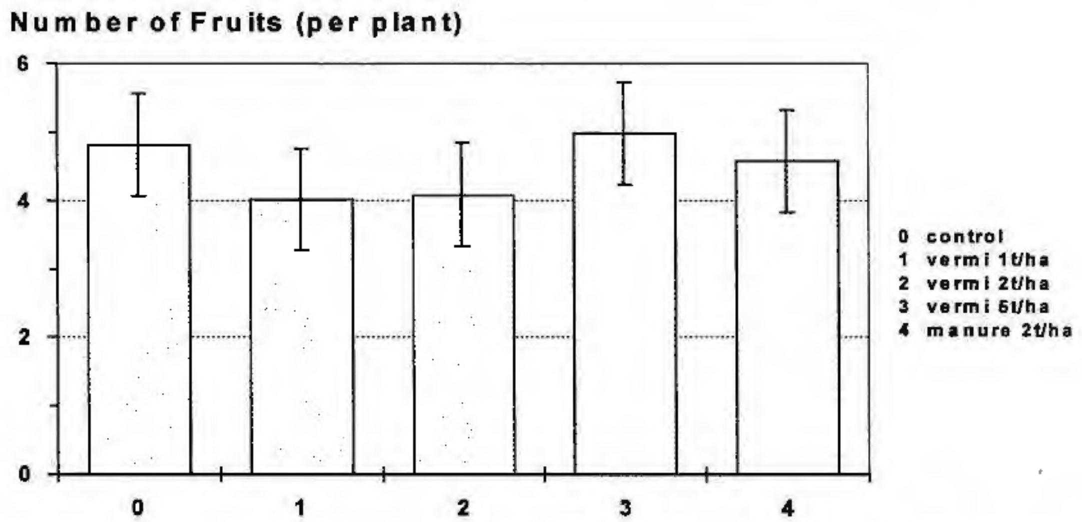

Fig. 1.6 - Number of fruits per plant, cotton with vermicompost/manure – Trial A - 16/12/97.

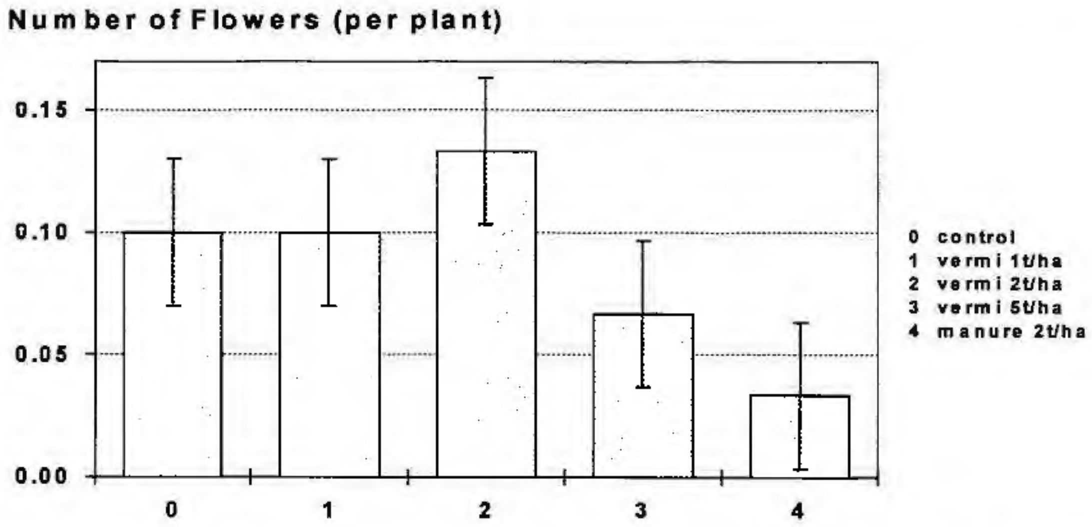

Fig. 1.7 - Number flowers per plant, cotton with vermicompost/manure – Trial A - 16/12/97.

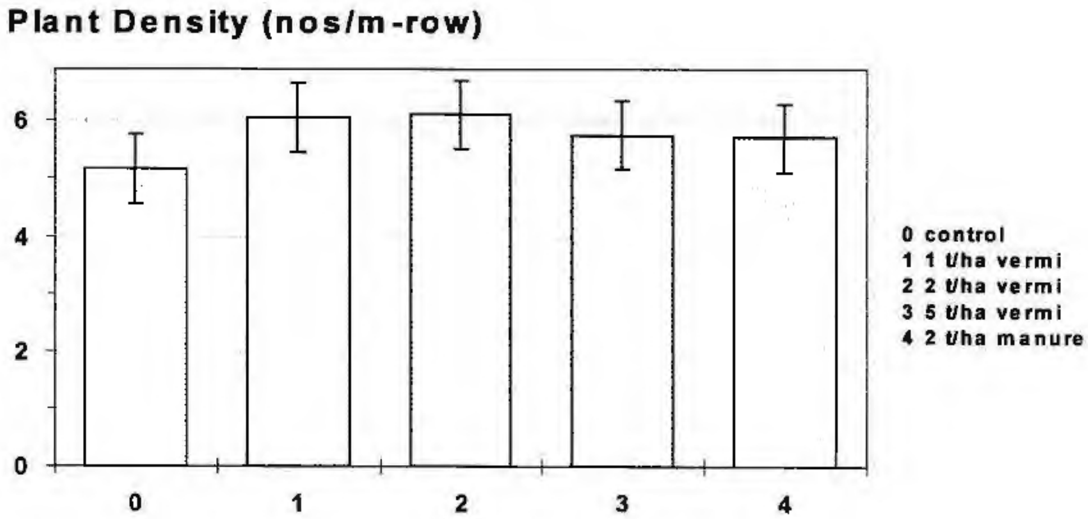

Fig. 1.8 - Plant density at harvest, cotton with vermicompost/manure – Trial A - 16/4/98.

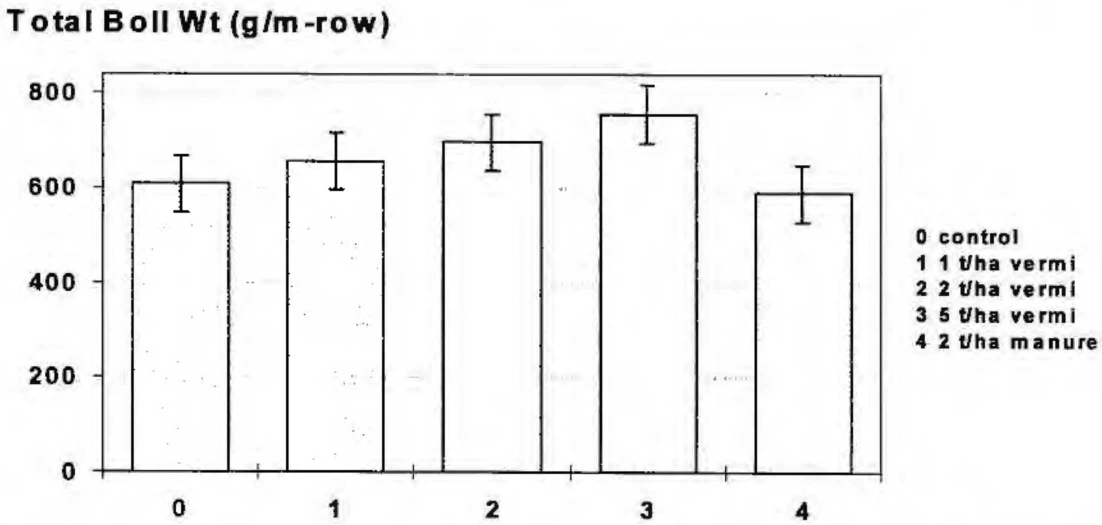

Fig. 1.9 - Boll weights at harvest, cotton with vermicompost/manure – Trial A - 16/4/98.

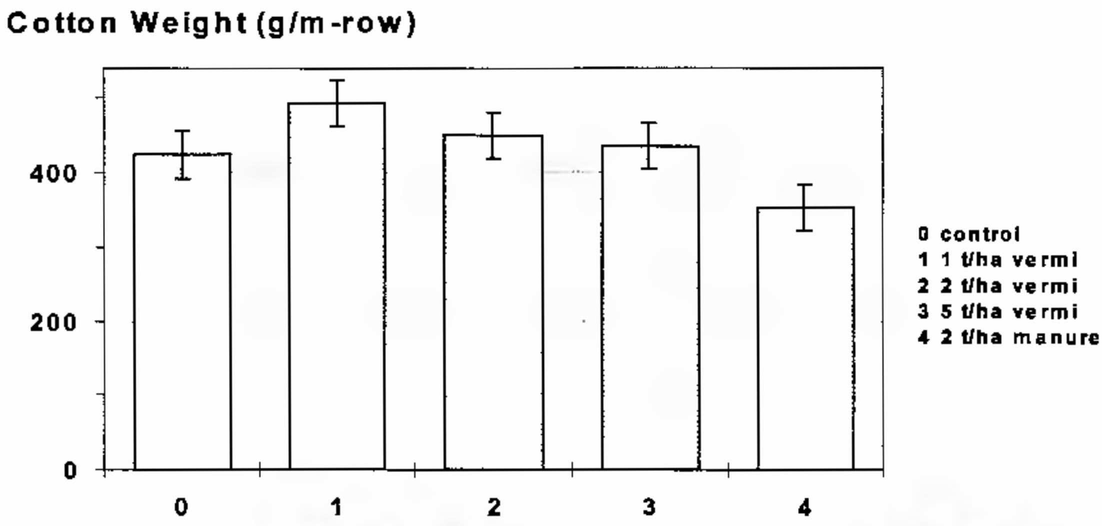

Fig. 1.10 - Cotton weight, cotton with vermicompost/manure – Trial A - 16/4/98.

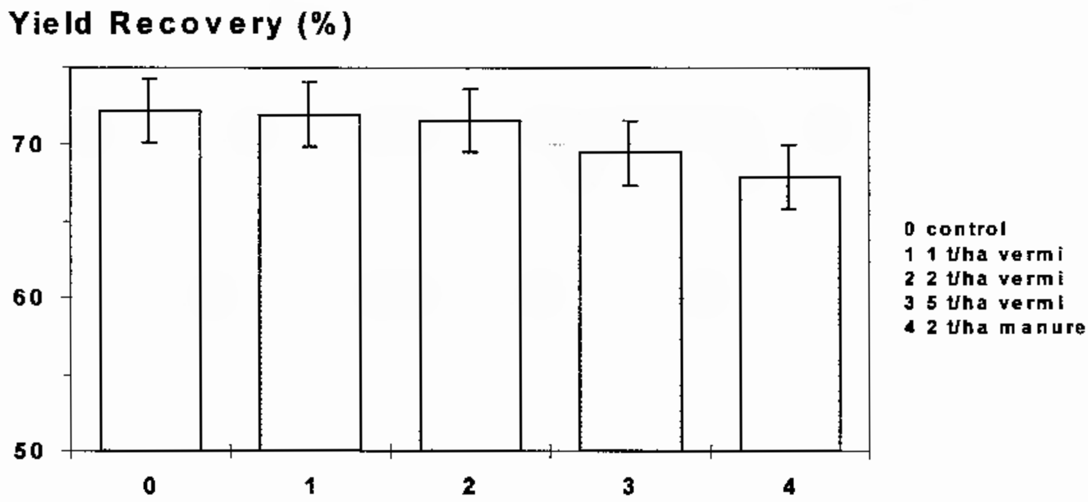

Fig. 1.11 - Cotton recovered from bolls, with vermicompost/manure – Trial A - 16/4/98.

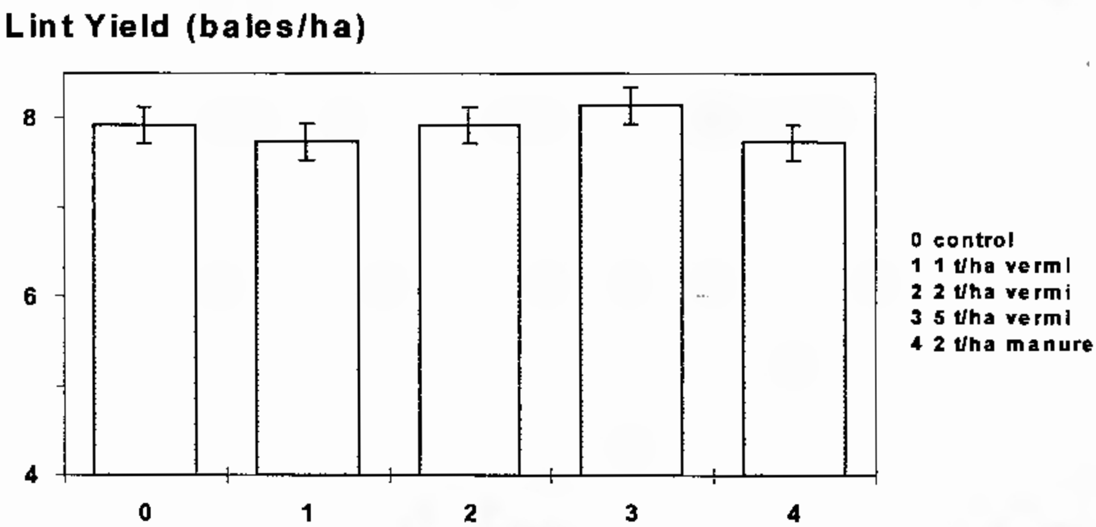

Fig. 1.12 – Lint yields at harvest, cotton with vermicompost/manure – Trial A - 16/4/98.

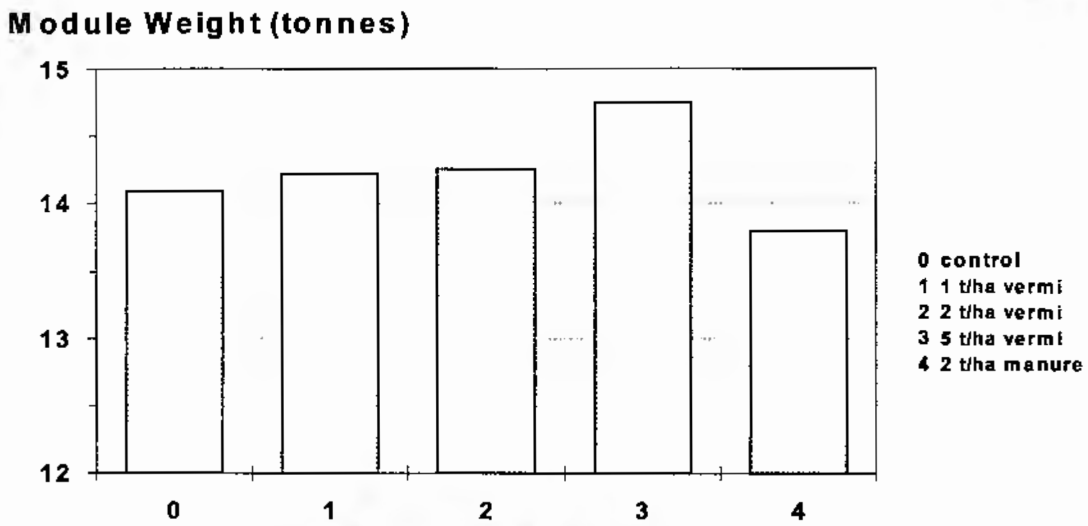

Fig. 1.13 - Module weights at harvest, cotton with vermicompost/manure – Trial A - 16/4/98.

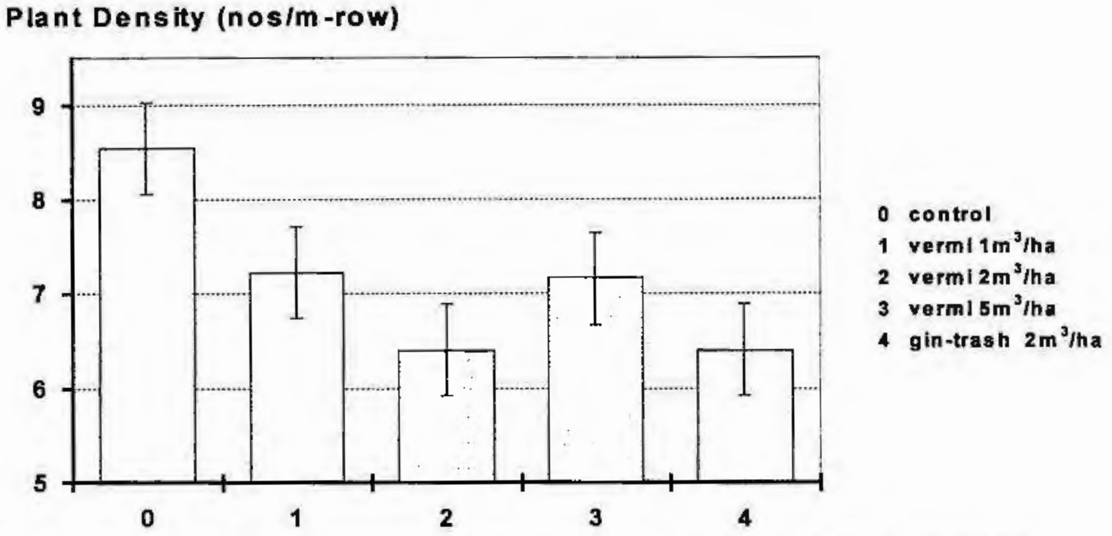

Fig. 2.1 - Establishment of cotton with vermicompost/gin-trash - Trial B - 12/12/98.

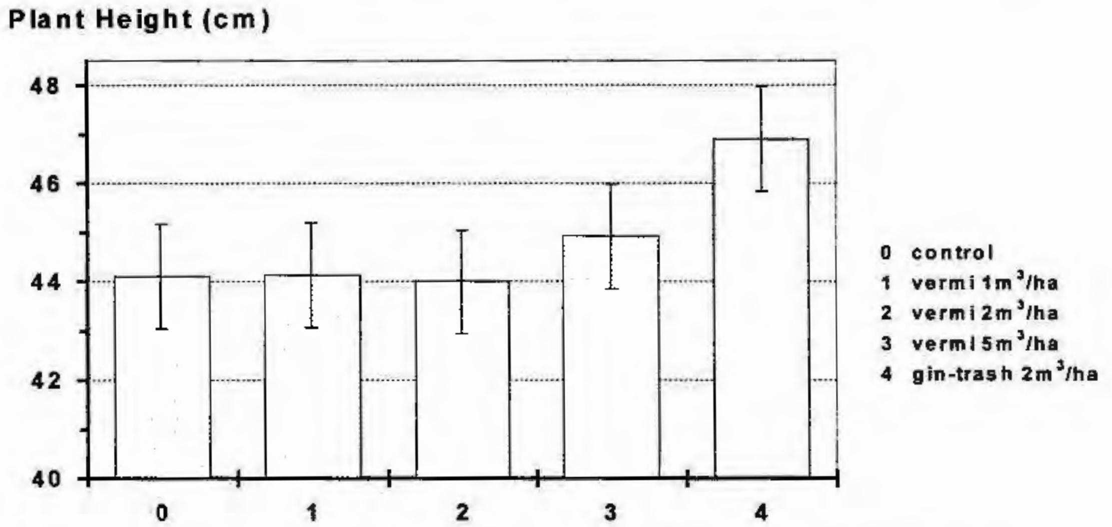

Fig. 2.2 - Plant height of cotton with vermicompost/gin-trash - Trial B - 12/12/98.

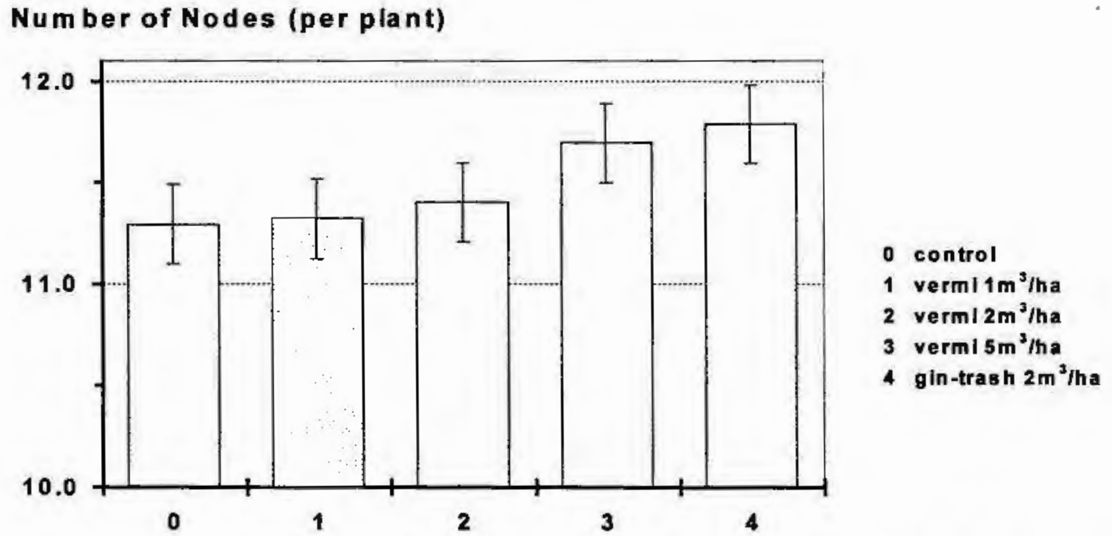

Fig. 2.3 - Number of nodes per plant, cotton with vermicompost/gin-trash - Trial B - 12/12/98.

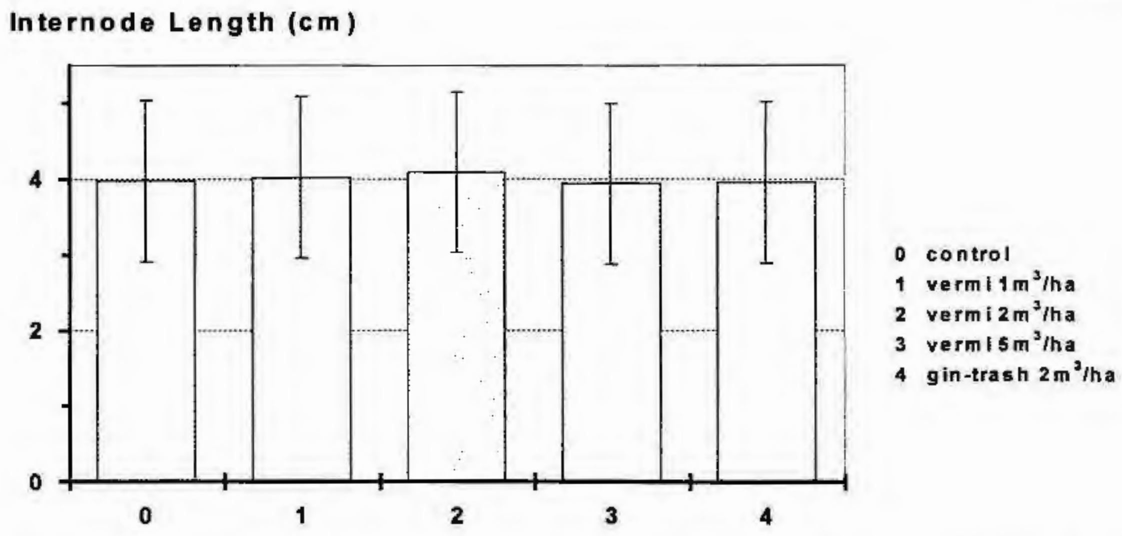

Fig. 2.4 - Average internode length, cotton with vermicompost/gin-trash - Trial B - 12/12/98.

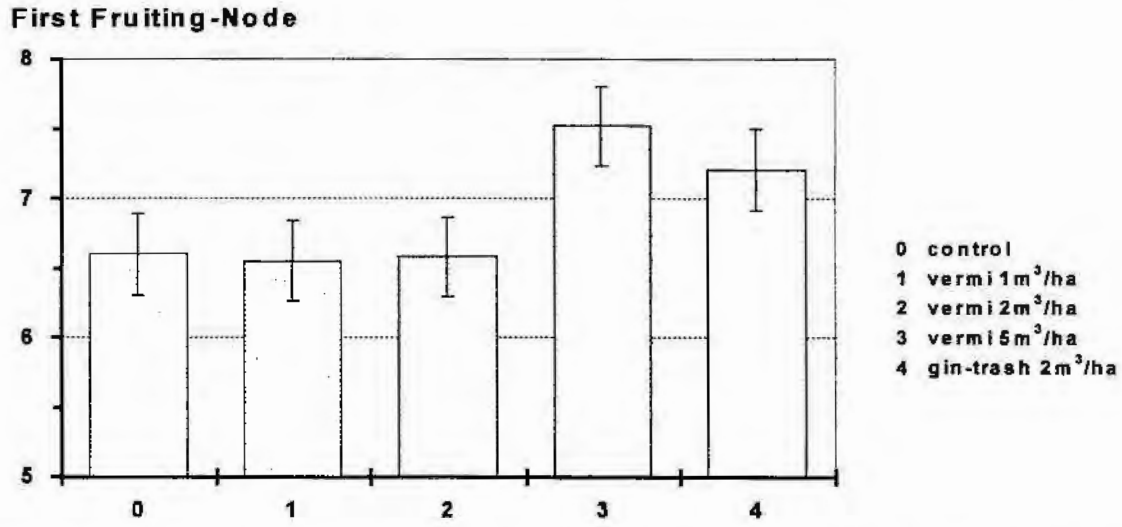

Fig. 2.5 - Position of first fruiting-node, cotton with vermicompost/gin-trash - Trial B - 12/12/98.

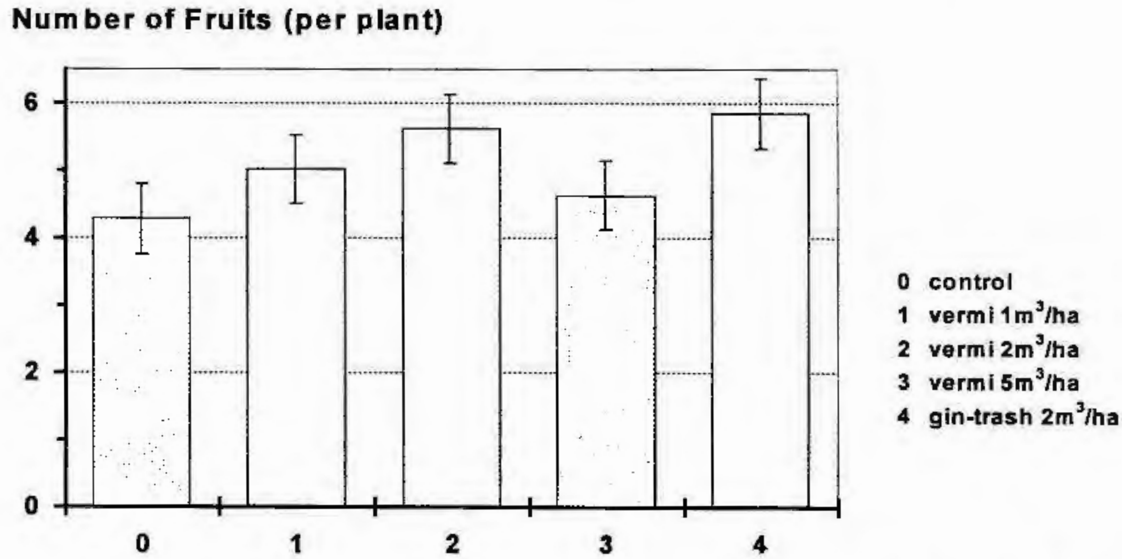

Fig. 2.6 – Number of fruits per plant, cotton with vermicompost/gin-trash - Trial B - 12/12/98.

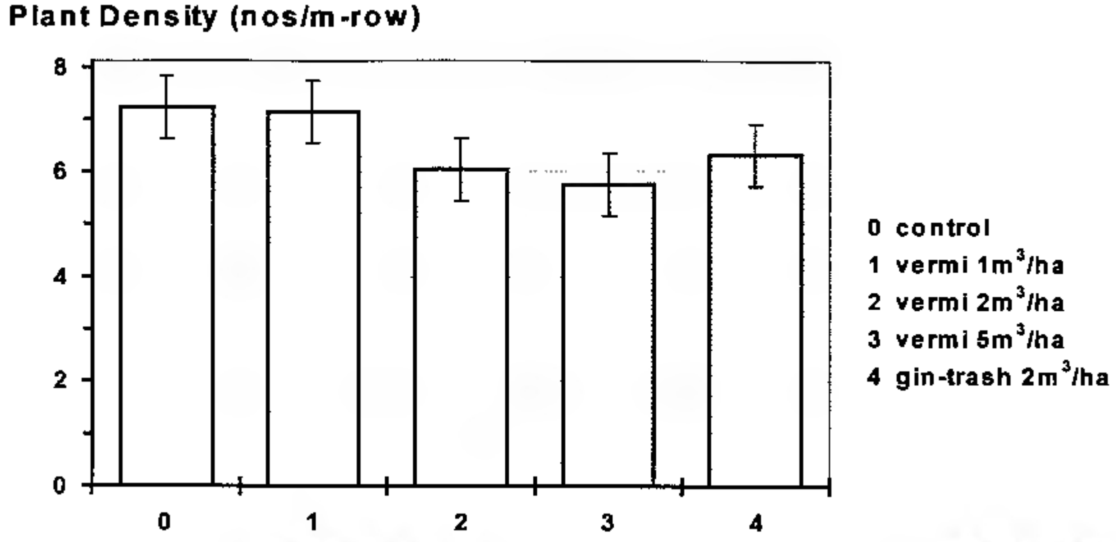

Fig. 2.7 - Plant density of cotton at harvest; vermicompost/gin-trash - Trial B - 17/4/99.

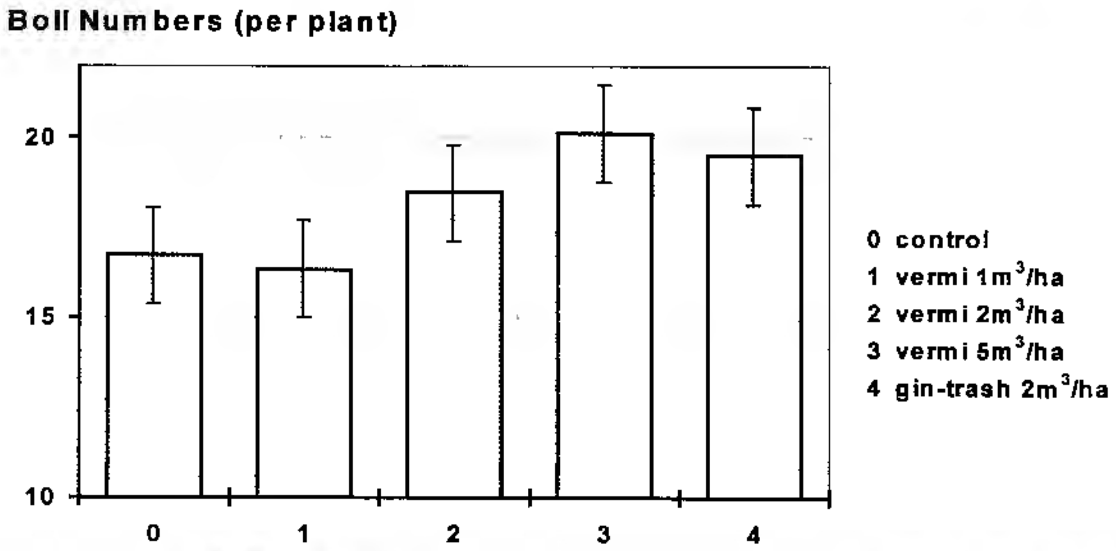

Fig. 2.8 - Cotton boll numbers at harvest; vermicompost/gin-trash - Trial B - 17/4/99.

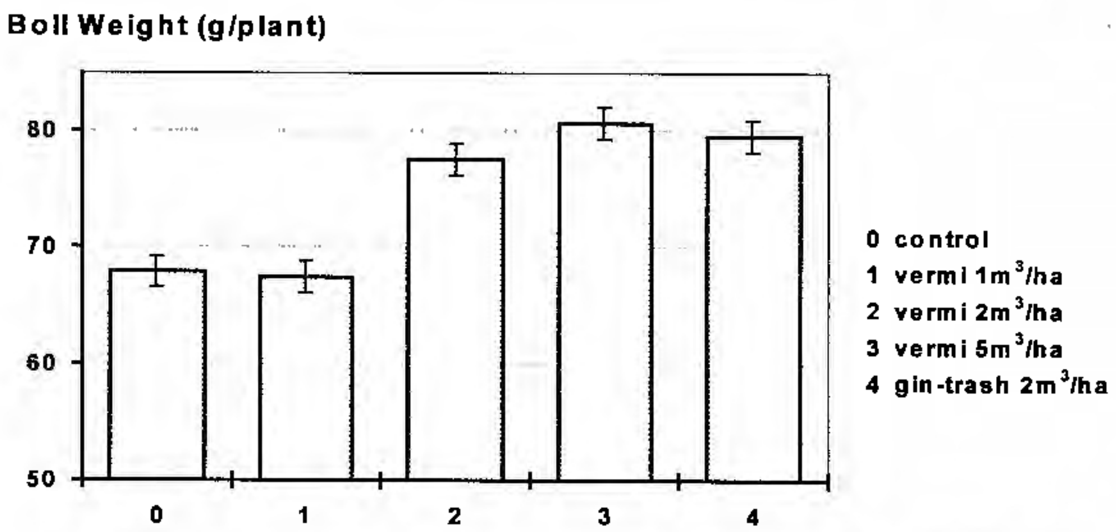

Fig. 2.9 - Cotton boll weights at harvest; vermicompost/gin-trash - Trial B - 17/4/99.

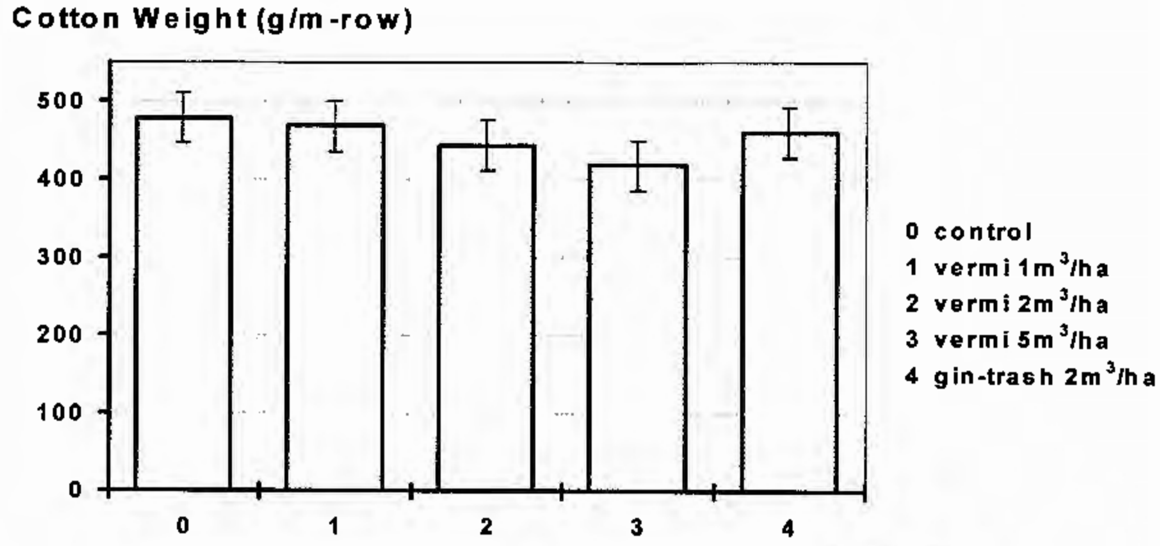

Fig. 2.10 - Cotton harvest yields; vermicompost/gin-trash - Trial B - 17/4/99.

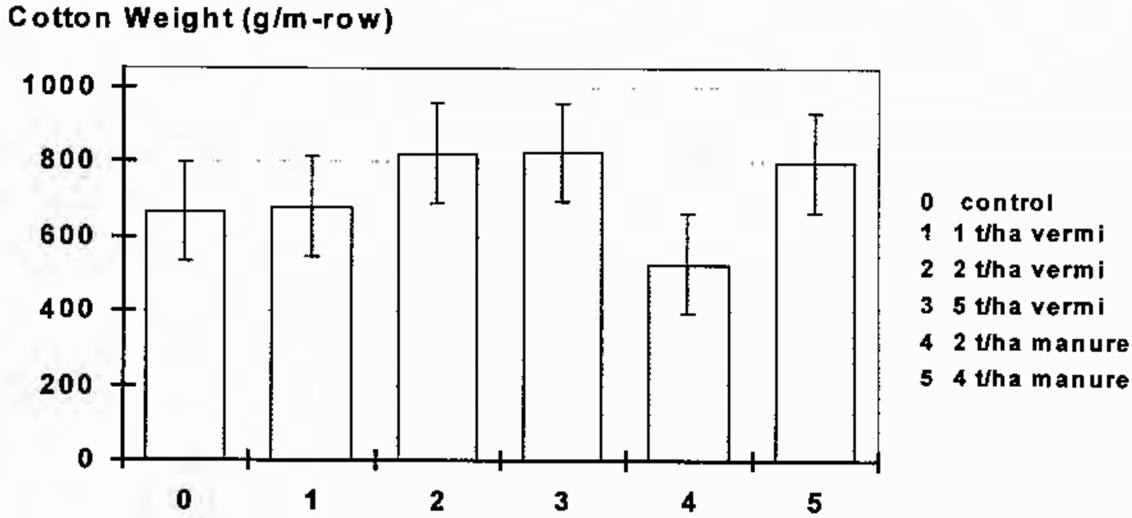

Fig. 2.11 - Cotton harvest yields; vermicompost/manure - Trial A (Block 3) - 18/4/99.

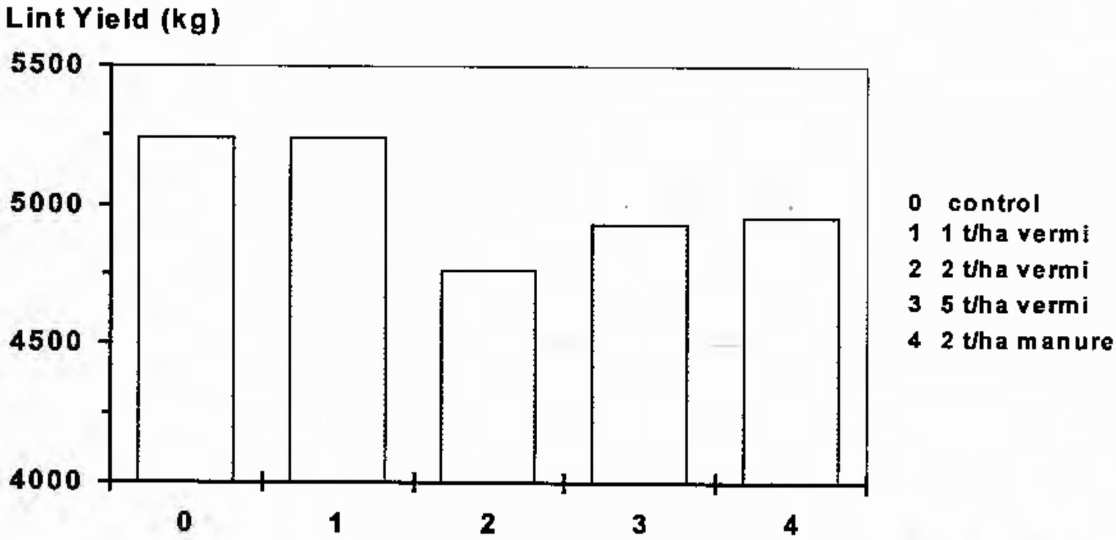

Fig. 2.12 - Cotton lint yields; vermicompost/manure - Trial A (Block 2) - 18/4/99.

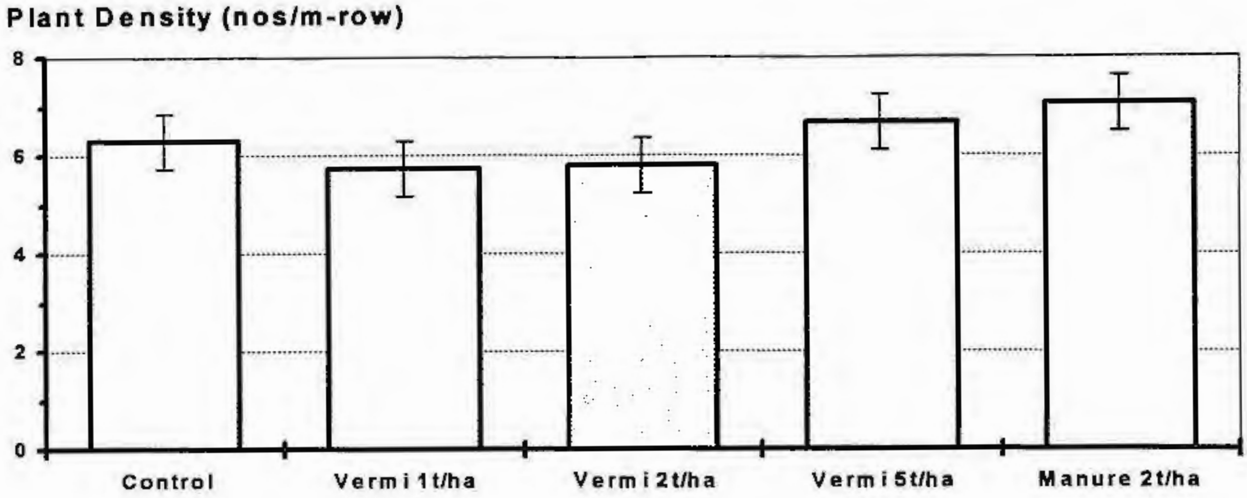

Fig. 3.1 - Plant density of cotton; vermicompost/gin-trash - Trial A – 20/02/00.

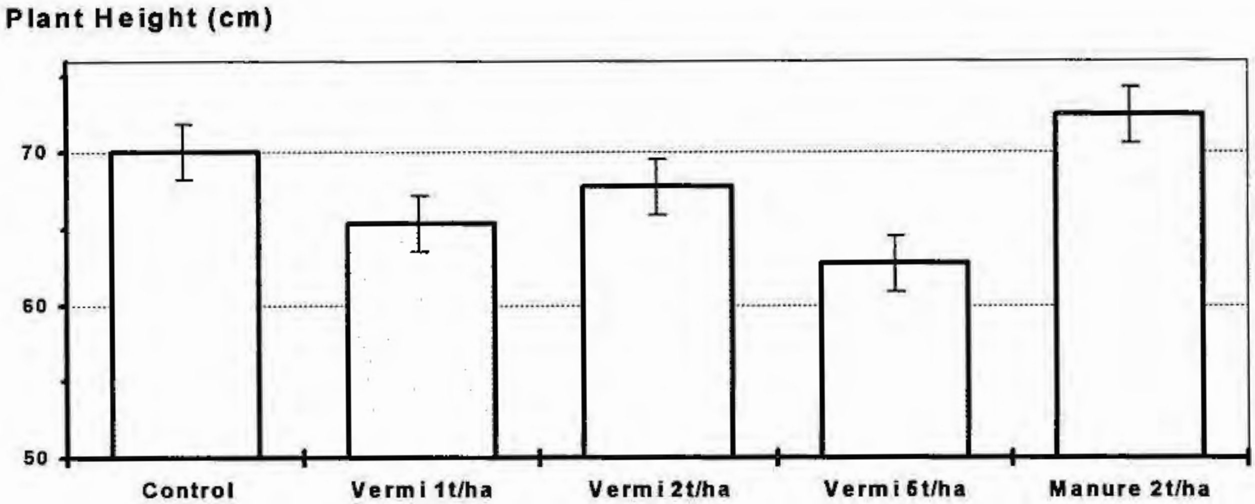

Fig. 3.2 - Plant height of cotton; vermicompost/gin-trash - Trial A – 20/02/00.

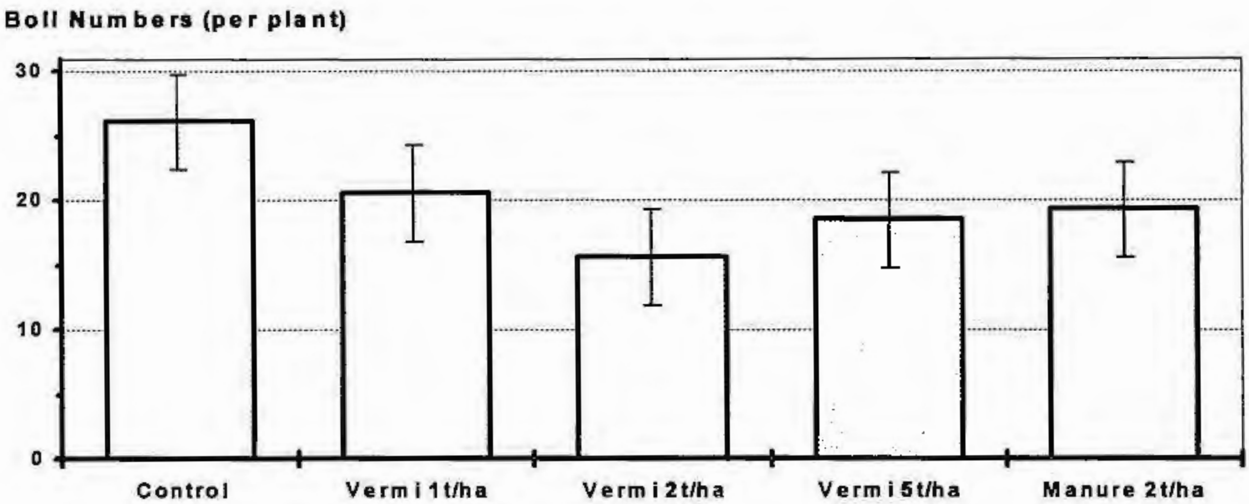

Fig. 3.3 – Boll number per plant; vermicompost/gin-trash - Trial A – 20/02/00.

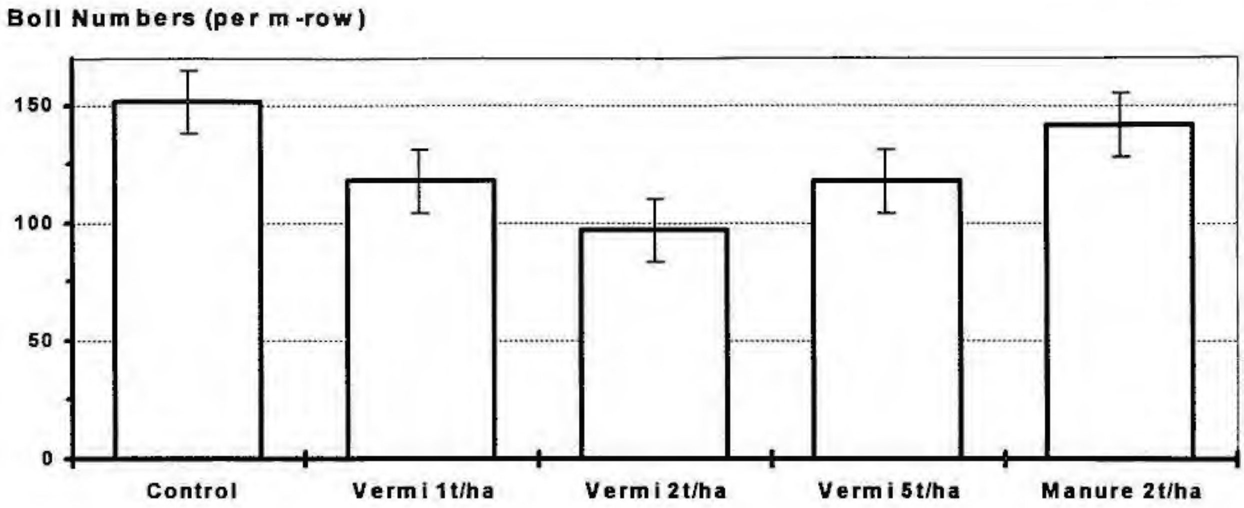

Fig. 3.4 - Boll density of cotton; vermicompost/gin-trash - Trial A – 20/02/00.

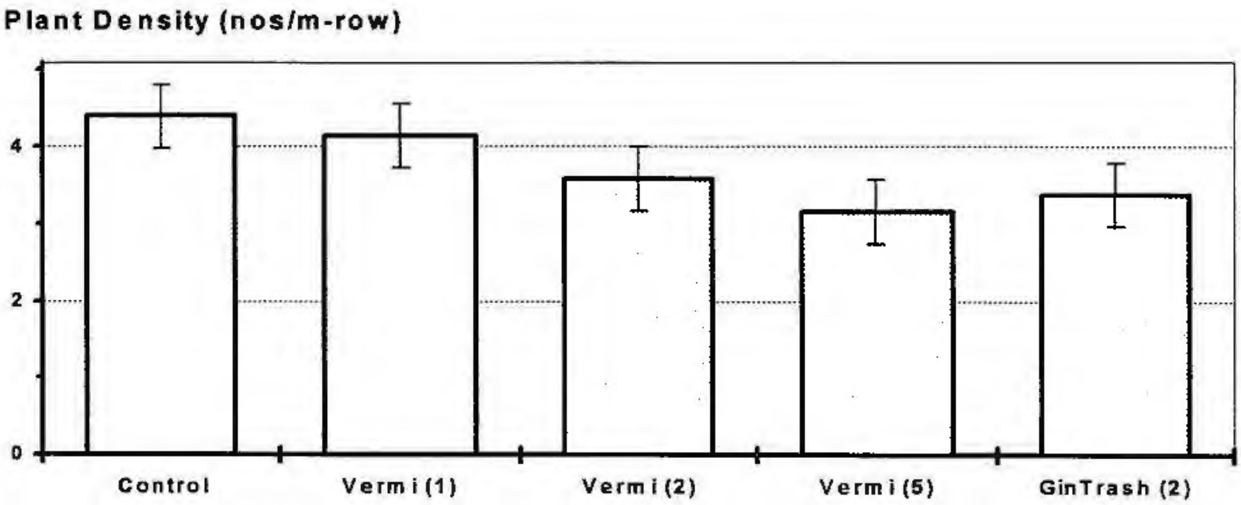

Fig. 3.5 - Plant density of cotton; vermicompost/gin-trash - Trial B – 20/02/00.

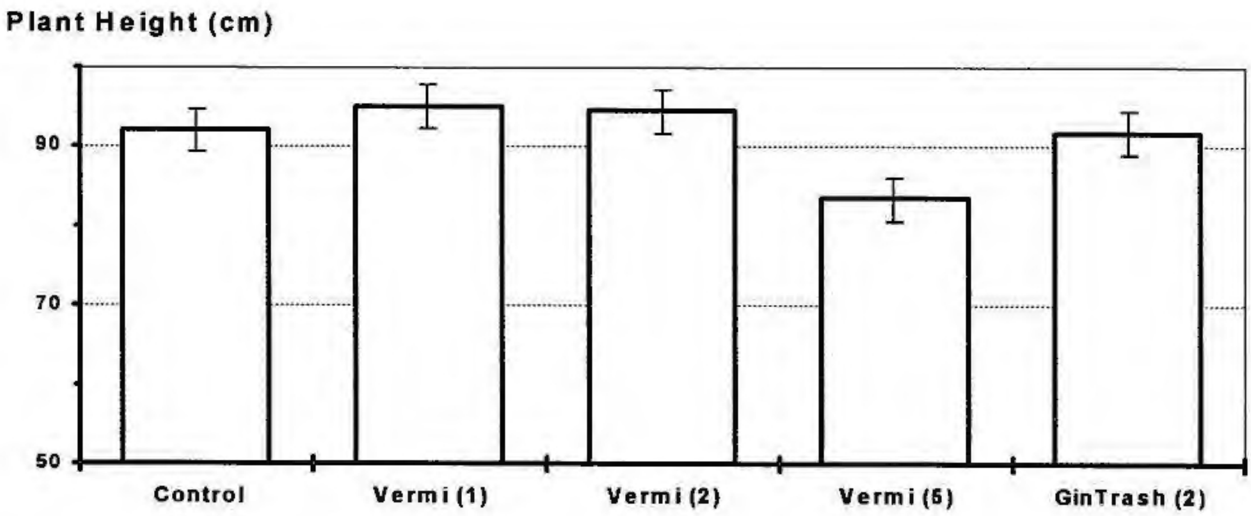

Fig. 3.6 - Plant height of cotton; vermicompost/gin-trash - Trial B – 20/02/00.

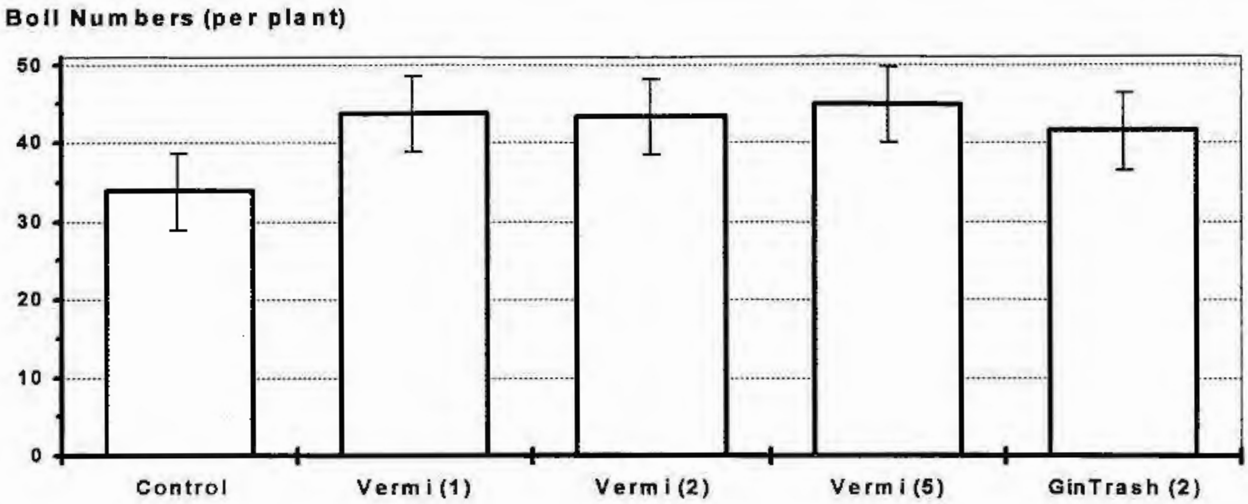

Fig. 3.7 – Boll number per plant; vermicompost/gin-trash - Trial B – 20/02/00.

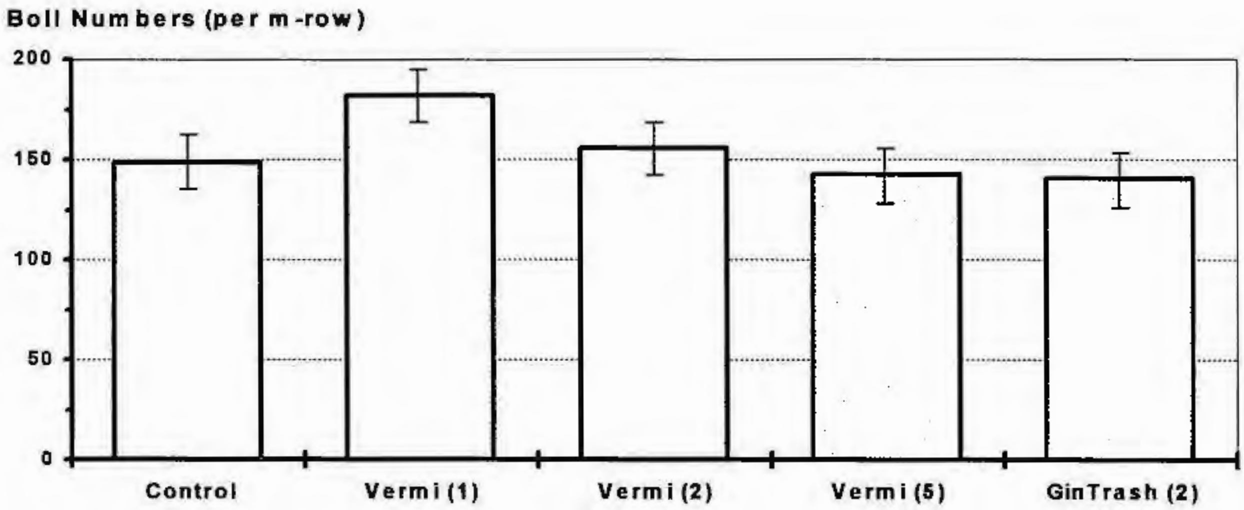

Fig. 3.8 - Boll density of cotton; vermicompost/gin-trash - Trial B – 20/02/00.

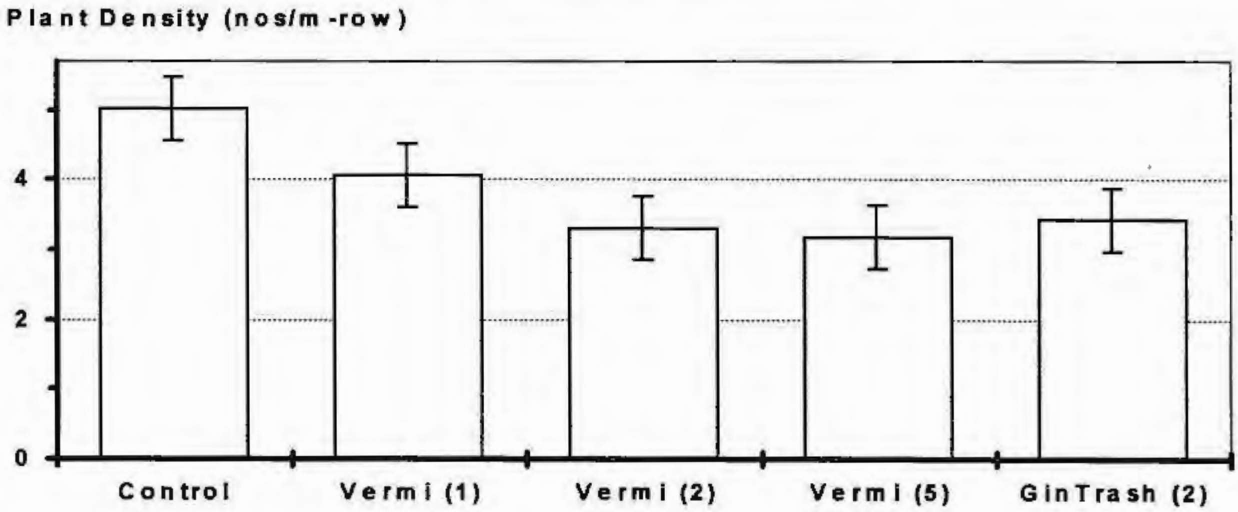

Fig. 3.9 - Plant density of cotton at harvest; vermicompost/gin-trash - Trial B – 12/04/00.

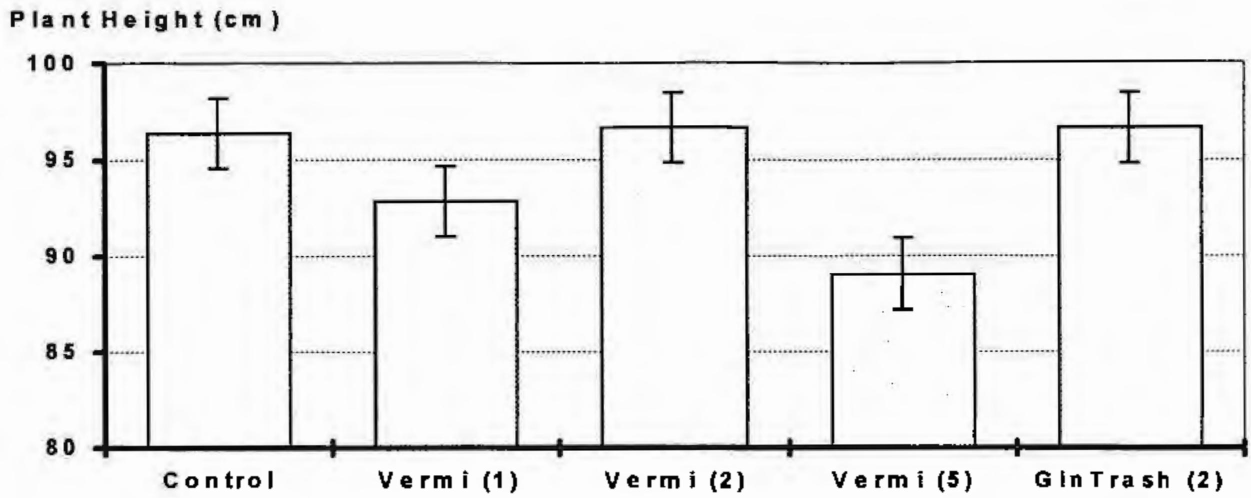

Fig. 3.10 - Plant height of cotton at harvest; vermicompost/gin-trash - Trial B – 12/04/00.

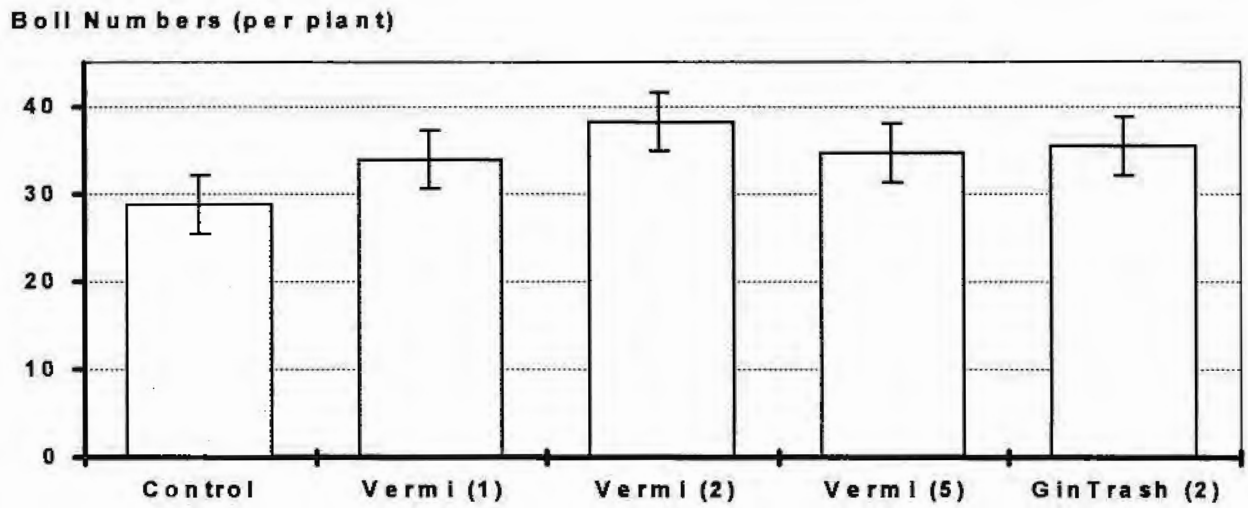

Fig. 3.11 – Boll number per plant at harvest; vermicompost/gin-trash - Trial B – 12/04/00.

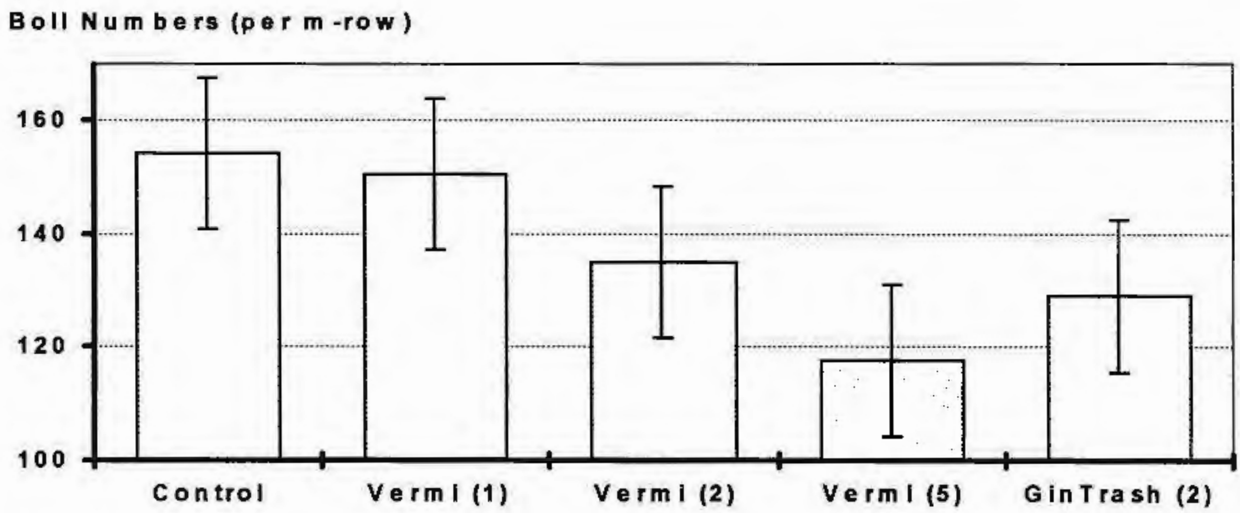

Fig. 3.12 - Boll density of cotton at harvest; vermicompost/gin-trash - Trial B – 12/04/00.

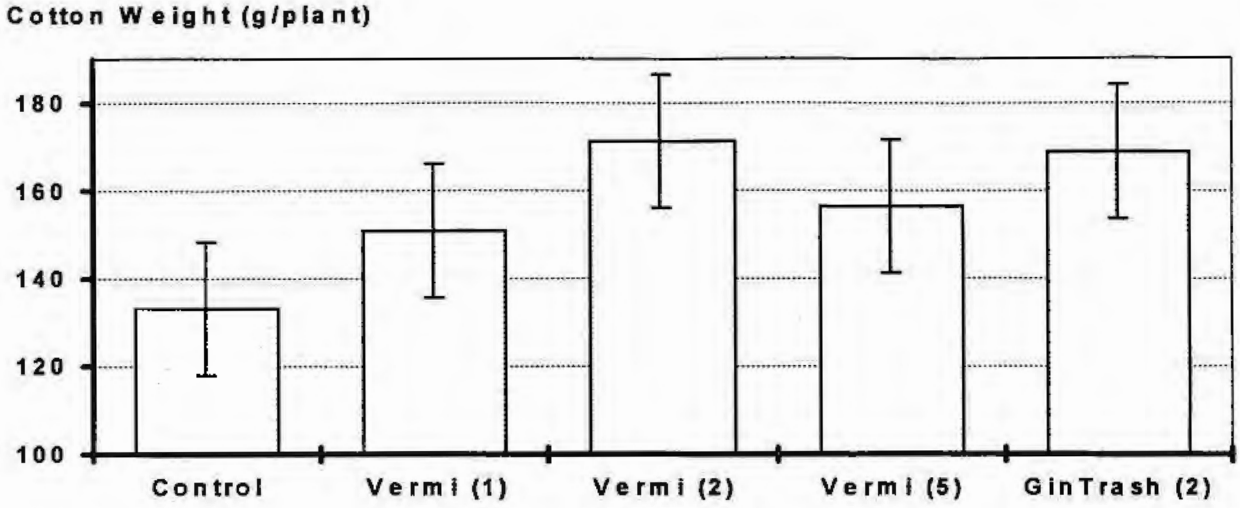

Fig. 3.13 - Cotton yields per plant at harvest; vermicompost/gin-trash - Trial B – 12/04/00.

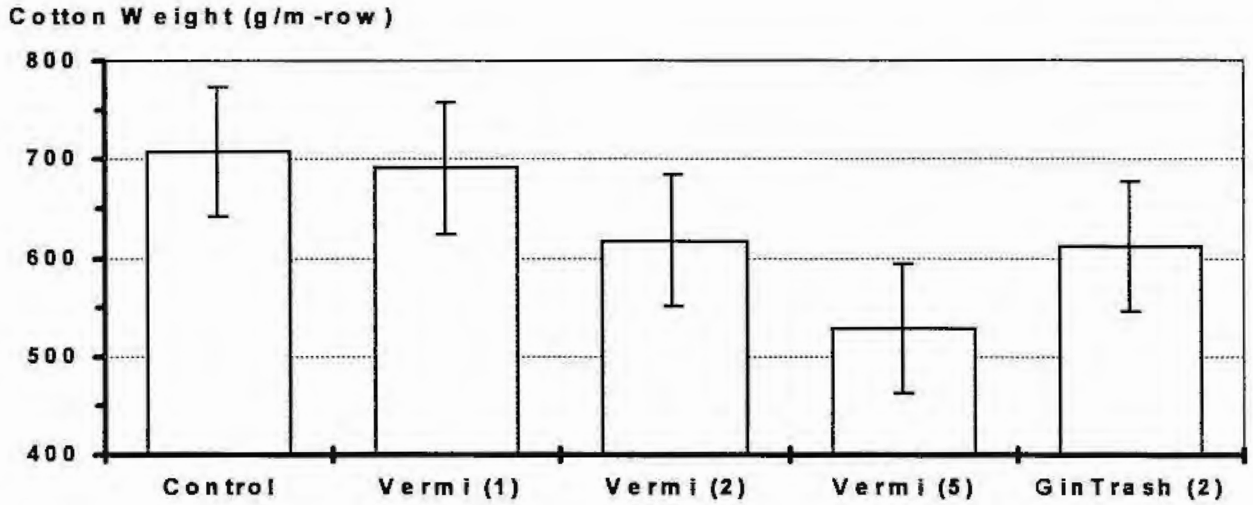

Fig. 3.14 - Cotton yields at harvest; vermicompost/gin-trash - Trial B – 12/04/00.

Control = Normal Practice, Vermi (1) = 1m^3/ha vermicompost, Vermi (2) = 2m^3/ha vermicompost, Vermi (5) = 5m^3/ha vermicompost, Gin Trash (2) = 2m^3/ha composted gin-trash.

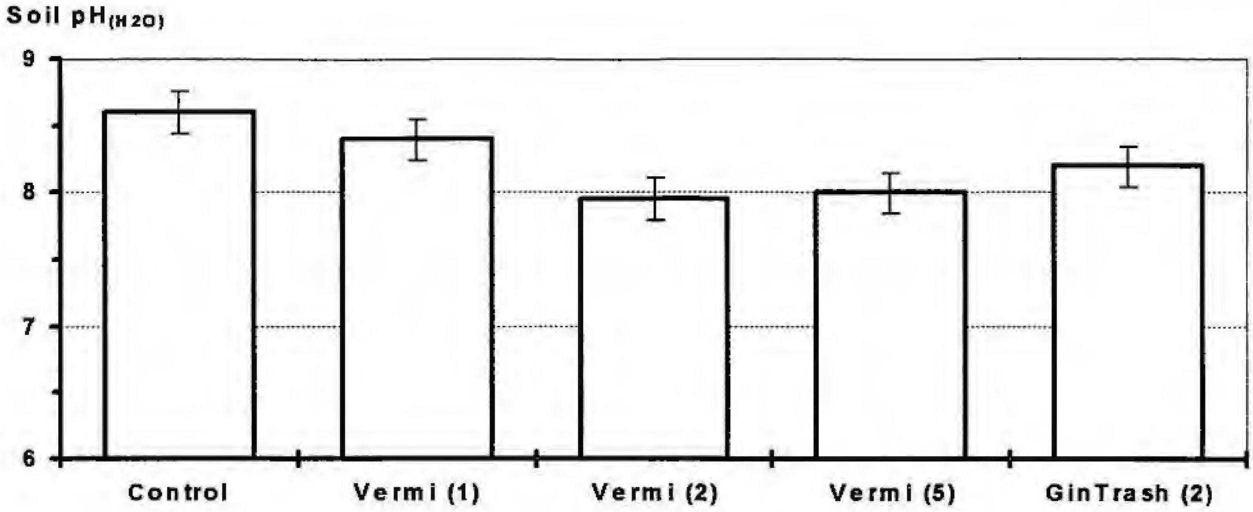

Fig. 4.1 - Soil $pH_{(H20)}$ under cotton, vermicompost/gin-trash Trial B - Moree, NSW.

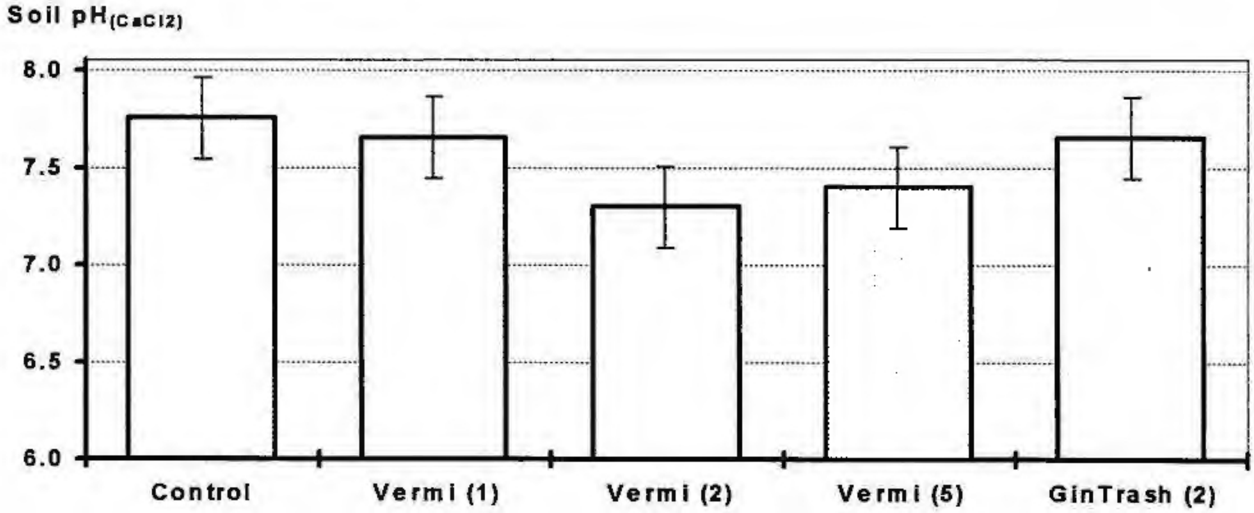

Fig. 4.2 - Soil $pH_{(CaCl2)}$ under cotton, vermicompost/gin-trash Trial B - Moree, NSW.

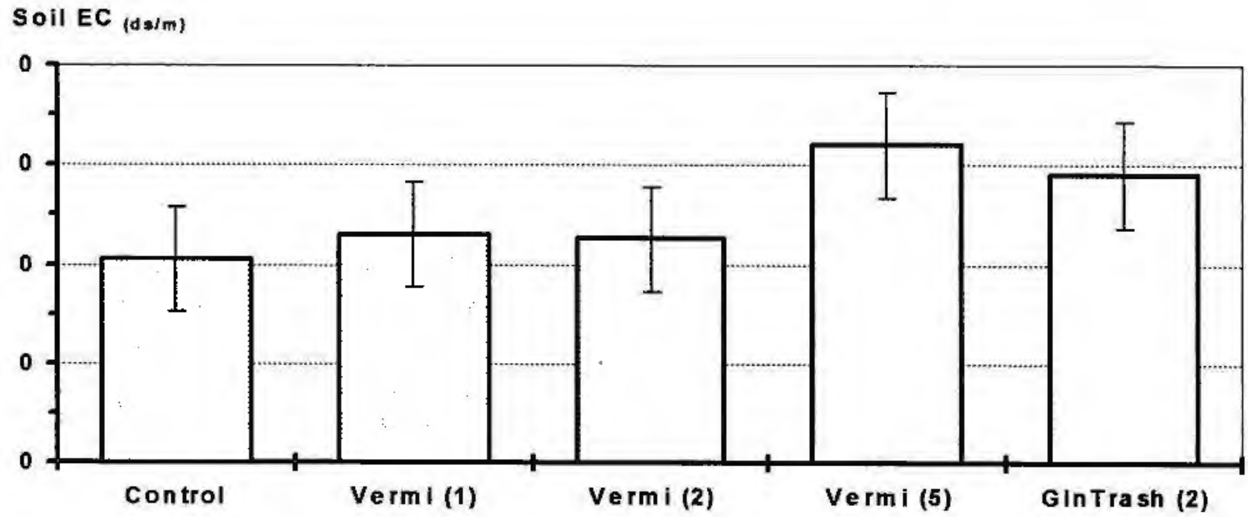

Fig. 4.3 – Soil $EC_{(1:5)}$ under cotton, vermicompost/gin-trash Trial B - Moree, NSW.

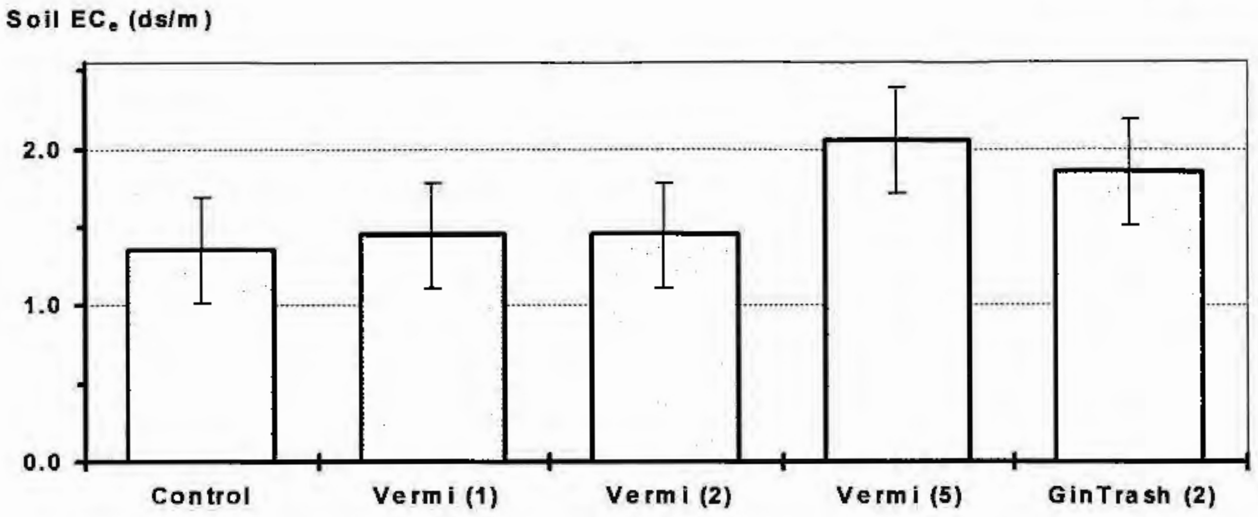

Fig. 4.4 - Soil EC_e (est) under cotton, vermicompost/gin-trash Trial B - Moree, NSW.

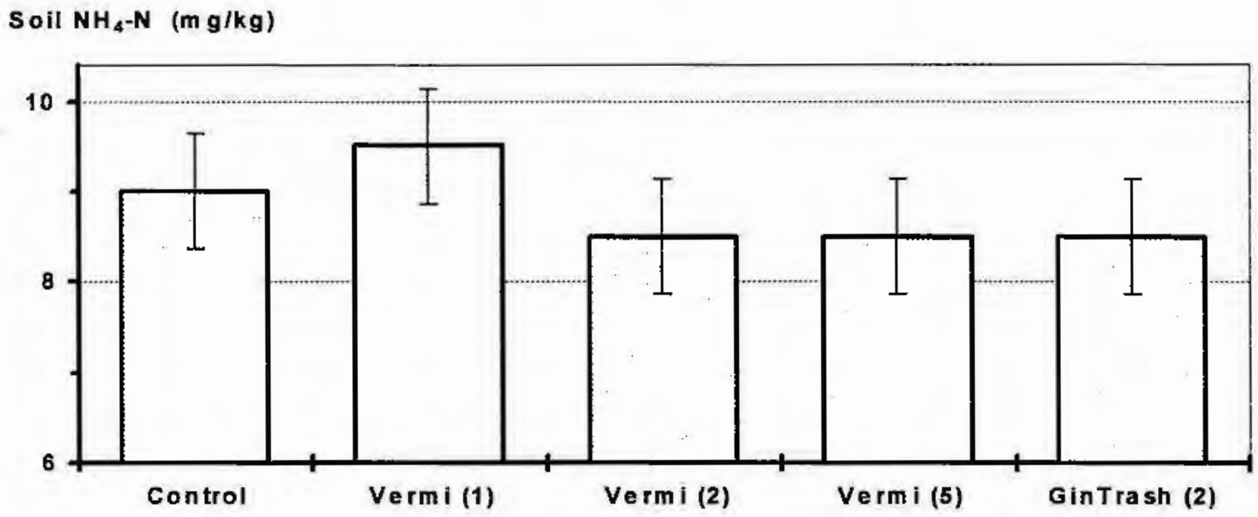

Fig. 4.5 - Soil ammonium-nitrogen under cotton, vermicompost/gin-trash Trial B - Moree, NSW.

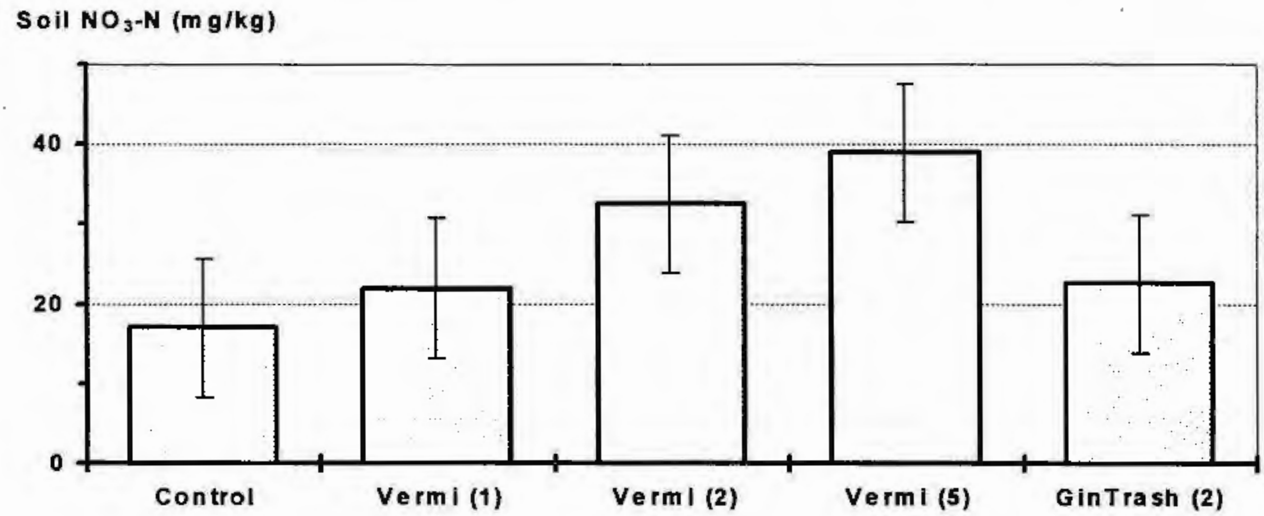

Fig. 4.6 - Soil nitrate-nitrogen under cotton, vermicompost/gin-trash Trial B - Moree, NSW.

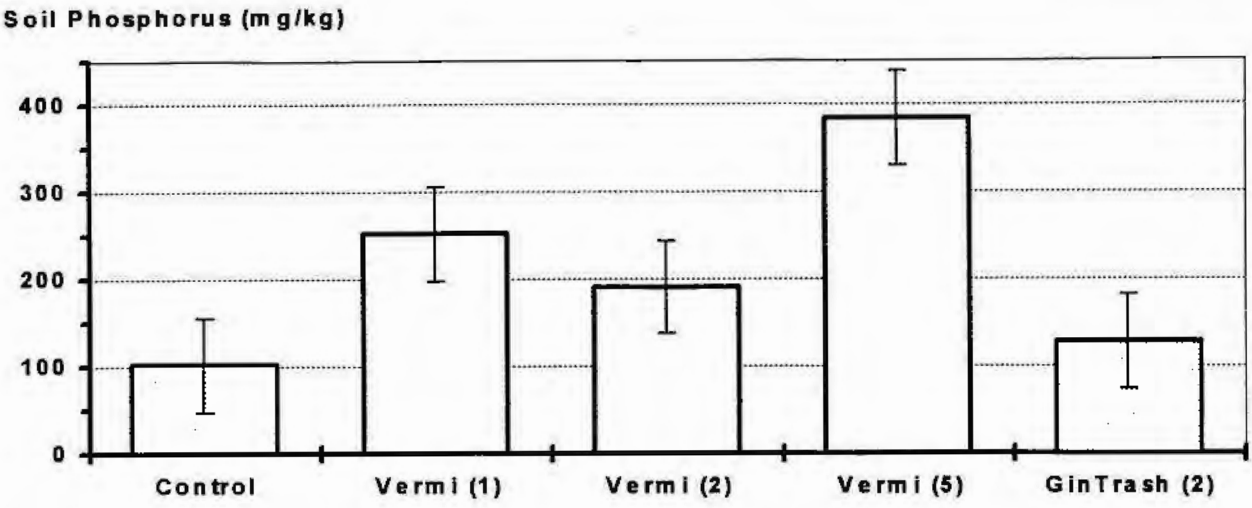

Fig. 4.7 – Soil phosphorus under cotton, vermicompost/gin-trash Trial B - Moree, NSW.

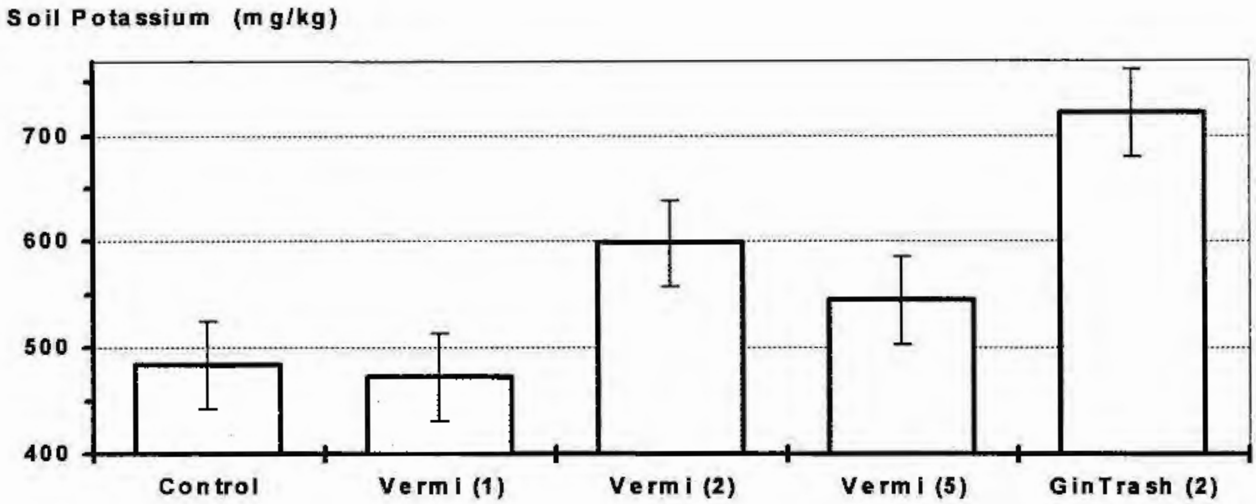

Fig. 4.8 - Soil potassium under cotton, vermicompost/gin-trash Trial B - Moree, NSW.

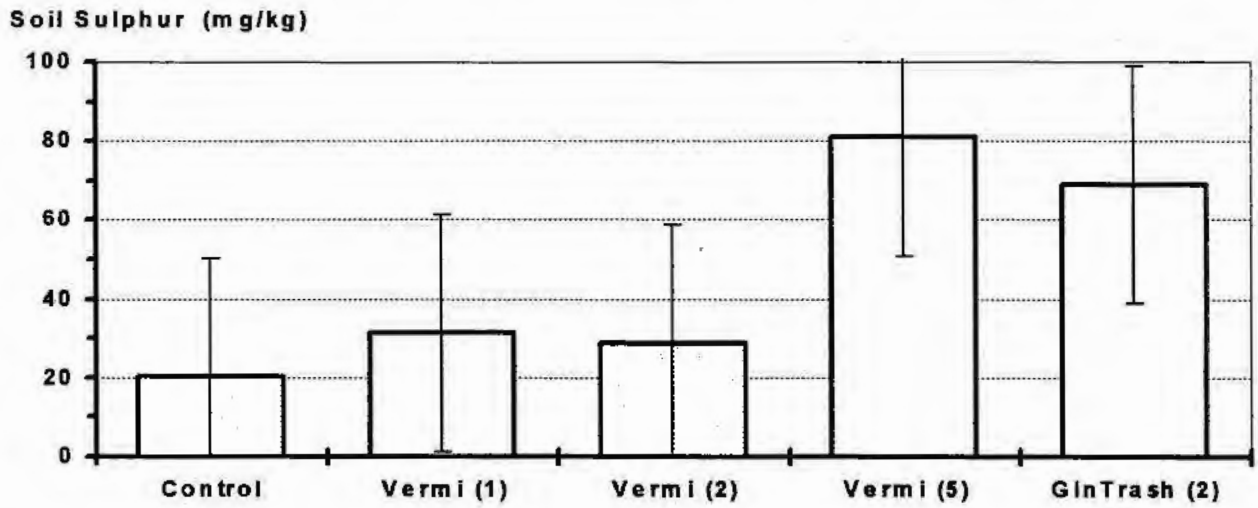

Fig. 4.9 - Soil sulphur under cotton, vermicompost/gin-trash Trial B - Moree, NSW.

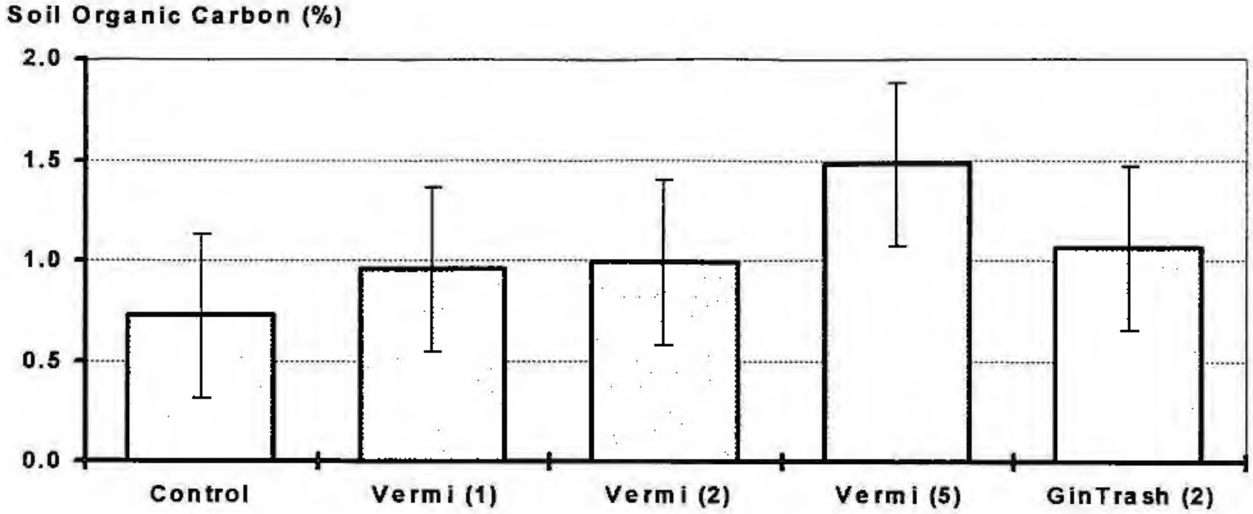

Fig. 4.10 - Soil organic carbon under cotton, vermicompost/gin-trash Trial B - Moree, NSW.

Control = Normal Practice, Vermi (1) = 1m^3/ha vermicompost, Vermi (2) = 2m^3/ha vermicompost, Vermi (5) = 5m^3/ha vermicompost, Gin Trash (2) = 2m^3/ha composted gin-trash.