Identifying the benefits of composted soil amendments to vegetable production

Bob Paulin
Department of Agriculture
Western Australia

Project Number: VG990016

Know-how for Horticulture™

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Waste Management Board

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VG990016

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MEDIA SUMMARY

A major national project to evaluate the benefits of compost to vegetable production has demonstrated compost consistently increases marketable yield and improves soil quality. Its continued use will build soil nitrogen and carbon, increase soil biological activity and cation exchange capacity, increase water holding capacity, reduce bulk density and stabilise pH. This leads to increased returns and benefits for growers, the environment and the wider community.

When transplanting leafy crops good quality compost has been shown to elevate plant available nitrogen increasing yields and potentially allowing major reductions in applied fertiliser. Root crops were shown to be sensitive to compost quality and yield and quality increases were not as dramatic. To gain the full advantage of using compost on these crops it will be necessary to adjust fertiliser programs to account for the improved soil fertility.

Improved marketable yield and savings in fertiliser alone have been sufficient to return extra dollars particularly on light sandy soils. The greatest benefits arise when its regular use effectively ‘bullet proofs’ the soil against unanticipated climatic events, irrigation or equipment failure and human error that would otherwise result in loss of potential yield.

This is because compost increases soil organic matter which increases the soils ability to:

- Hold crop available nutrients and water.
- Maintain and improve soil aeration and drainage; and
- Maintain optimal pH and reduce erosion.

One of the most important findings has been the ability of compost to increase the supply of plant available nitrogen and potentially reduce the need for large amounts of inorganic nitrogen. It contains useful quantities of plant available phosphorus, potassium and magnesium and the nitrogen it contains is retained in the soil and is available for future crop use. To achieve full benefits growers will need to incorporate the use of compost into their normal management programs and the report acknowledges that a number of changes and developments are needed before growers will use compost on a large scale.

The findings highlight the potential for compost to contribute to the development of ’best practice’ production systems that further improve productivity by making better use of fertiliser, irrigation and pesticides and that produce more consistent, better quality crops with less impact on soil and ground water quality.

The level of improvement in soil and crop performance that can be achieved by using compost will depend on the concentration at which soil carbon reaches equilibrium within the applied management system. The report discusses the need to change management practices to increase soil organic matter levels further and achieve greater potential benefits.

Aspects of compost quality that improve its performance have been identified and made available to the composting industry. However the challenge to the composting industry is to implement quality management that will consistently deliver the quality required for vegetable production.

In the short term, achieving greater use of compost by the vegetable industry relies on reducing its cost. Since the benefits of use extends to the wider community through assisting the beneficial reuse of organic wastes, increasing the proportion of cost borne by the waste producers will provide a mechanism to reduce cost.

TECHNICAL SUMMARY

This project was established to quantify and promote the benefits of using compost in Australian vegetable production. Vegetable production faces multiple challenges of improving productivity, meeting growing demands for 'safe, clean and green' produce and managing increasing costs and competition while demonstrating sustainable use of soil and water resources.

Both urban communities and agriculture are also being challenged to implement 'zero waste' principals that include environmentally and socially acceptable recycling of their wastes. This project therefore explores the potential for utilising principally organic wastes to the benefit of both agriculture and the wider community.

The research and development program involved fertiliser replacement, production system evaluation and commercial demonstration sites. A series of nutrient replacement trials were established to determine the adjustment in fertiliser program required to accommodate nutrients provided by compost. Replicated split plot experiments were established to evaluate the nitrogen (both WA and Victoria), phosphorus and potassium (WA only) contributions from a commercial urban greenwaste based compost, applied at 0, 30 and 60 m^3/ha. The nutrient under investigation at each trial site was applied at five rates from 0 to 125% of commercial practice and other nutrient requirements were applied in accordance with current best practice. Crop rotation reflected regional commercial practice and where possible combined a root and leafy crop.

The System evaluation trial site in WA allowed comparison of three independently irrigated soil management strategies involving conventional inorganic best practice, compost and compost combined with clay soil amendment. Compost was applied at 30 m^3/ha prior to each crop and the clay content in the clay amended plots was adjusted to 5% in the top 15 cm, prior to trial commencement. In Victoria the focus was on the use of composts made from different feedstocks and the resultant impact on compost quality and performance.

In WA, the sandy soils allowed the installation of lysimeters at both the fertiliser and system sites and combined with electronic tensiometers, allowed detailed monitoring of both irrigation and nutrient management in selected treatments.

In all but one of the 17 trials conducted, yields improvement was indicated. Based on the cheapest fertiliser chemicals, savings in nitrogen, phosphorus and potassium, together with other key nutrients, initially accounted for half of the typical cost of applying compost and with continued use, savings increase to two thirds of the applied cost.

Significant improvements, particularly on the sandy soils, were noted in all soil characteristics measured, including increased soil organic matter, organic nitrogen, biological activity and diversity, cation exchange capacity, volumetric soil moisture along with improved soil pH and reduced bulk density. The addition of clay at the system site further added to both crop and soil performance.

Gross marginal analysis indicated that the use of compost in vegetable production will increase returns. Further when events such as irrigation failure and or unseasonal conditions resulted in crop stress, the improvements to soil performance associated with regular compost use had the potential to produce large increases in crop and therefore returns.

The potential for vegetable production and other horticultural crops to reuse large volumes of reclaimed water from waste water treatment plants creates a need to establish permanent areas or precincts for horticultural production. Apart from challenging the current planning process of continuous urbanisation, the protection of groundwater quality within these precincts will require changes to the current farming system. Combining the reuse of organic wastes to improve soil organic matter and soil performance with the adoption of better management will significantly increase the level of groundwater protection that can be achieved.

Despite the demonstrated improvement in returns, growth in the use of compost in vegetable production continues to be limited. Results at commercial demonstration sites have also generally been positive, but in reality the increases achieved have not been sufficient to overcome:

- cost and a reluctance to alter existing management practices;
- difficulties with making adjustments to fertiliser program; and
- requirements for storing and spreading compost and growers' limited experience with its successful use coupled to either first or second hand experiences with poor quality compost.

Results from the PhD program at the University of Western Australia confirmed that compost makes a significantly greater contribution to the development of soil organic matter than poultry manure. However, the reality is that while there is unrestricted access to low cost raw manures the higher cost and lower nitrogen availability of compost will significantly limit its use by most growers.

Progress is being made in developing suitable application equipment and positive results associated with compost use in an increasing range of crops are accumulating. The current national Compost Roadmap Project, with a focus on developing agricultural compost markets, will assist and potential changes to policies governing the application of organics to land will address some of the competitive inequities that currently reduce compost's competitiveness.

The mobility of inorganic nitrogen in all soils and its impact on groundwater quality is a major challenge for vegetable production. While losses will be reduced by further improving fertiliser and irrigation practices, the use of compost will increase and maintain soil nitrogen and organic matter and provide significant additional capacity to manage nitrogen loss and to use less nitrogen.

Greater research and development focus on 'Carbon based vegetable production' to further increase soil organic matter levels will maximise the potential to reduce nitrogen, irrigation and pesticide usage.

Work to develop these systems will usefully integrate aspects of cover cropping, permanent bed production (Rogers 2002) and possibly sub-surface irrigation with compost use to develop lower input, high performance production systems that better meet the combined needs of greater productivity, better resource protection and the production of safe healthy fresh food.

INTRODUCTION

The aim of this project and previous work undertaken by the Department of Agriculture, Western Australia has and continues to be the development of:

- Productive vegetable (horticultural) production based on using compost to build and maintain soil organic matter; and
- These industries as a sustainable market for the reuse of organic wastes from agricultural and urban sources.

This project followed on from a one year project funded by Horticulture Australia, then HRDC, VG 98079 'Soil amendments to improve vegetable production on sandy soils' (Paulin 1999), and was the outcome of a national workshop in Adelaide in 1998. At this workshop, participants divided into two groups that worked on the:

- Use of compost in horticulture – resulting in this project; and
- Soil management regimes based on rotation and cover cropping – resulting in the project VG 98050 'Development of a sustainable integrated permanent bed system for vegetable production including sub-surface irrigation extension' by Gordon Rogers *et al*. (Rogers 2002).

The project 'Developing productive vegetable production based on the use of composted soil amendments' commenced in 2000/01. It had three components that were conducted in Western Australia, Victoria and at the University of Western Australia:

- Quantifying the nutritional benefits of composted soil amendments in terms of its contributions to crop requirements for nitrogen, phosphorus and potassium – Fertiliser Replacement Trials.
- Identifying elements of a production system that could maximise the economic benefits of using these materials in vegetable production – System trials; and
- Quantify potential improvements to crop quality and performance – all trials and grower demonstrations.

In Western Australia, the major component of the project, work was conducted on light sandy soils.

In Victoria a project team lead by Kevin Wilkinson carried out a reduced but similar program on heavy soils at the Knoxfield research site and on grower properties at Werribee.

The project funded a PhD studentship at the University of Western Australia to investigate aspects of biological activity, soil health and fertility associated with the use of composted soil amendment in vegetable production. The studentship was awarded to Tamara Flavel and while focussing on the coarse sands in Western Australia, elements of the work were carried on heavy soils at the Victorian Knoxfield site.

The project acknowledged the potential for soil organic matter to contribute to productive vegetable production in a number of ways and sought to quantify them in order to encourage the use of compost in commercial vegetable production. While the focusing on improved productivity in terms of marketable yield and fertiliser savings, the production system element of the Western Australian work also investigated potential irrigation savings.

There is extensive literature on compost, its production and use and this was reviewed when the Department of Agriculture, WA commissioned the study by Tingay @ Associates (Tingay 1997). The report titled 'Potential use of soil amendments in horticulture', underpinned the commencement of investigations into how compost could be used in horticulture to improve productivity and provide a sustainable market for the reuse of organic wastes. Further reviews were conducted in conjunction with this and the previous HRDC funded project submissions.

While supporting the potential for compost to improve most if not all aspects of vegetable production, these studies highlighted the need to investigate and quantify within a local context, the range of benefits and to consider management changes that could maximise these benefits. In addition to quantifying benefits in terms of crop production and fertiliser use, the project was also established to:

- Further develop our understanding of critical compost quality requirements.
- Quantify improvements to irrigation use.
- Identify improvement to soil performance, health and fertility; and
- Contribute to economically, environmentally and socially sustainable outcomes for vegetable production.

Growing environmental concerns associated with vegetable production in particular arise from its intensive management and continuous cropping, frequent proximity to estuaries and other environmentally sensitive areas, its extensive use of irrigation that often utilises unconfined aquifers for self irrigation and the nature of soils used (Paulin *et al*. 1995). While the nutrient concerns initially focussed on phosphorus, nitrogen has now become the main focus.

Vegetable production on the sandy soils of the Swan coastal Plain in Western Australia utilise very high levels of nitrogen fertilisers and frequently applying 300 and 400 kg per ha per crop. With crop recovery rarely better than 25% and between two to three crops per year, losses on nitrogen to ground water are significant.

It is increasingly acknowledged that soil organic matter is capable of making a significant contribution to the nitrogen requirements of vegetables and that for this to become a reality, more emphasis on building soil organic matter levels is necessary.

Composting is an essential step in the process of building and maintaining soil organic matter levels because it provides a mechanism for managing risks of introducing disease, weeds and pests as well as other contaminants that are inevitably associated with organic wastes. The composting process typically requires blending of different feedstocks for best process management and this also provides opportunity to manage heavy metal and other contaminants by dilution as well as mechanical means.

Organic materials typically comprise 50 to 60% of the total waste stream and their impact on greenhouse gas production, mainly methane and groundwater pollution emerged as major concerns. Recently the national consulting company, Noland ITU (August 2004) released a statement that the annual environmental cost of landfill associated with major Australian cities is an estimated $670m and that this is over twice their estimate of the National cost of salinity.

Outcomes from these concerns have resulted in various landfill reduction targets (in Western Australia a 50% reduction by 2000 was set) and from the outset, agriculture was recognised as a major potential market for the organic waste component.

However despite progress in some market sectors, most diversion targets proved to be unrealistic and around Australia these targets have been replaced with the concept of 'Zero Waste'. In Western Australia; the States Strategic Direction for Waste Management' released in August 2003 has endorsed a strategy that will work towards 'Zero Waste' by 2020.

An important component of the zero waste has been the general agreement on a Waste Management hierarchy based on principals of avoid, minimise, recycle and energy recovery as options with diminishing priority and disposal or land filling being considered the option of last resort. This hierarchy is summarised in Figure 1 and in this framework, energy recovery as well as landfill or disposal represent the failure to achieve zero waste.

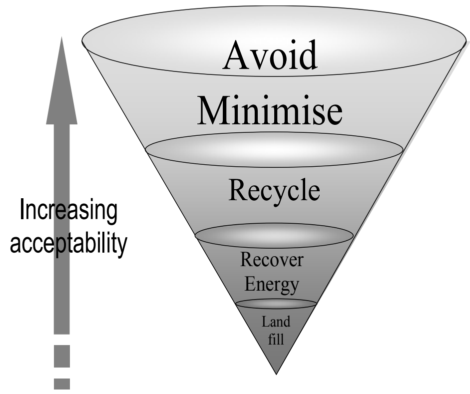


Figure 1. Hierarchy of acceptability for principal mechanisms of waste management.

Recycling organic waste to build soil organic matter has the potential to improve agricultural production and soil performance, to address organic waste management issues, and to better manage environmental and social concerns associated with agriculture.

SECTION 1 – FERTILISER REPLACEMENT TRIALS – WESTERN AUSTRALIA

Introduction

A series of trials were carried out over three years at the Medina Research Station to determine the Nitrogen, Phosphorus and Potassium fertiliser value of greenwaste, manure based compost applied to coarse sandy soil when growing lettuce and carrot in rotation.

Lettuce and carrots were selected as important crops grown on the Swan Coastal Plain and were grown in rotation, representing typical practice of alternating leaf and root crops in order to minimise disease build up.

Crop performance as total and marketable yields were measures along with changes to soil organic matter and other soil physical and chemical properties including bulk density, cation exchange, volumetric soil moisture and pH were made and lysimeters were installed under selected plots to enable nutrient cycling and leaching to be monitored.

Field research into the management of soil biological activity and related aspects of soil fertility in vegetable production was conducted in conjunction with a Post Graduate Doctoral Study supervised by the University of Western Australia. This program was undertaken at the Nitrogen Replacement trial site.

Materials and Method

The experiments to determine the fertiliser replacement value of compost were conducted on uncropped grey 'Grey phase' Karakatta sands (Bettenay *et al*. 1960) of low natural fertility at the Medina Research Centre. The top 10 to 15 cm of soil at the site was intensively soil sampled prior to commencing the trial program. The samples were analysed by the Government Chemistry Centre in Perth and the results are provided in Table 1.0.

Three separate but adjacent sites were established to determine the Nitrogen, Phosphorus and Potassium value of greenwaste, manure based compost for vegetable production. This was achieved by measuring the effect compost application had on crop response to different levels of applied nutrient. Diagrammatic representation of the overall research site at the Medina Research Station, including the System Trial Site is provided by Diagram 1.1 and the block layout of treatments for the series of fertiliser replacement trials, is shown in Diagram 1.2.

Each site had four replicated blocks of five main plots (two types of compost, one finished and one matured, at 30 and 60 cubic metres per hectare plus a zero control). Each main plot was subdivided into five sub plots to which five levels of either Nitrogen, Phosphorus or Potassium fertiliser was applied. Three crops of a lettuce, carrot rotation were grown on the Phosphorus and Potassium sites and seven on the Nitrogen site.

Main plots were 1.72 m wide (tractor width) and 42.75 m long, separated by a 0.53 m buffer. Each sub plot was 6 m long and separated by a 2.5 m buffer. After bed formation the top surface of each plot was approximately 1.2 m wide and a bed area of 1.2 x 6 m was used to calculate the inorganic fertiliser addition. Compost was applied evenly to the full area of the main plot before being incorporated into the top 10–20 cm of the bed.

Each site was irrigated by three lines of Nelson 'Windfighter' R2000 gold nozzle sprinklers set at 12 x 12 m square pattern and operated at 350 kPa.

Table 1.0. Soil analysis of to 15 cm of soil at the fertiliser replacement trial site at the Medina Research Station, prior to commencing the trial program

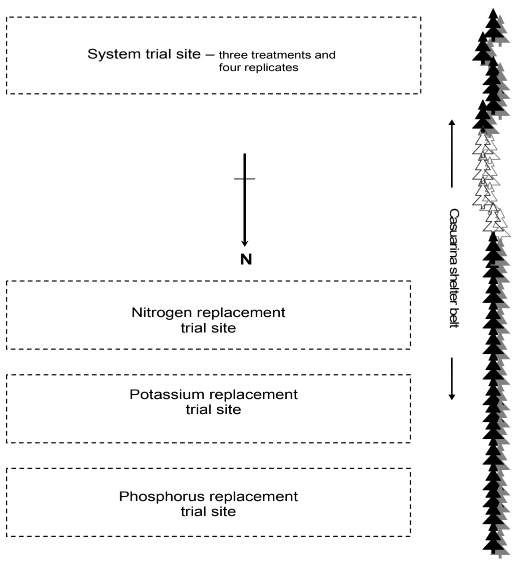
Analyte	Unit	Site		
		Nitrogen	**Phosphorus**	**Potassium**
Phosphorus ($HC0_3$)	mg/kg	14.8 ± 0.96	11.6 ± 1.44	
Total	mg/kg		69.2 ± 4.0	
Potassium ($HC0_3$)	mg/kg	13.40 ± 1.38		12.0 ± 1.8
Nitrogen (N) Total	%	0.028 ± 0.006		0.025 ± 0.005
N_(NH_4)	mg/kg	5.60 ± 0.77	3.7 ± 1.1	3.6 ± 1.0
N_(NO_3)	mg/kg	1.20 ± 0.44	2.0 ± 0.6	1.0 ± 0
Organic Carbon (W&B)	%	0.58 ± 0.16		
pH		5.80 ± 0.23	7.00 ± 0.43	6.40 ± 0.46
Exchangeable Cations**	Cmol(+)/kg	2.59 ± 0.56	2.59 ± 0.28	3.01 ± 0.77
Electrical Conductivity	mS/m	8.5 ± 1.1	10.8 ± 1.8	3.7 ± 1.0

* Values are averages of 12 composite samples ± Standard Deviation of 15-20 cores taken every 2 metres in a zig zag pattern across each site.

** ΣExch.(Ca + Mg + Na + K).

Compost

Diagram 1.1. Vegetable compost trial areas at the Medina research Station and layout of fertiliser replacement and the System trials (not to scale).



Efforts were made to ensure that the compost used would be suited to use in vegetable production. The compost was sourced from a single producer supplying a premium product for vegetable production over the entire trial program and analysis for each of the batches used is provided in Appendix 1.1.

The compost used was made primarily from urban green waste and caged layer or broiler chicken manure and had been finished to two maturity levels. The compost was produced in open windrows over 12 to 14 weeks. It was turned using a windrow turner in response to core temperature, moisture and oxygen levels. On delivery to the trial site, half of the compost was then placed in a covered concrete bunker and further matured for two to three months. During this period, core temperatures and moisture levels were monitored and it was turned using a front-end loader at approximately two weekly intervals. With the exception of the first nitrogen replacement trial, the two levels of compost maturity were achieved by using the current delivered compost (A) and the previously delivered compost (B) that has been further processed during the life of the previous crop. Compost along with basal fertiliser requirements were applied and incorporated with a rotary hoe into the top 10 cm of soil, 7 to 10 days prior to crop establishment.

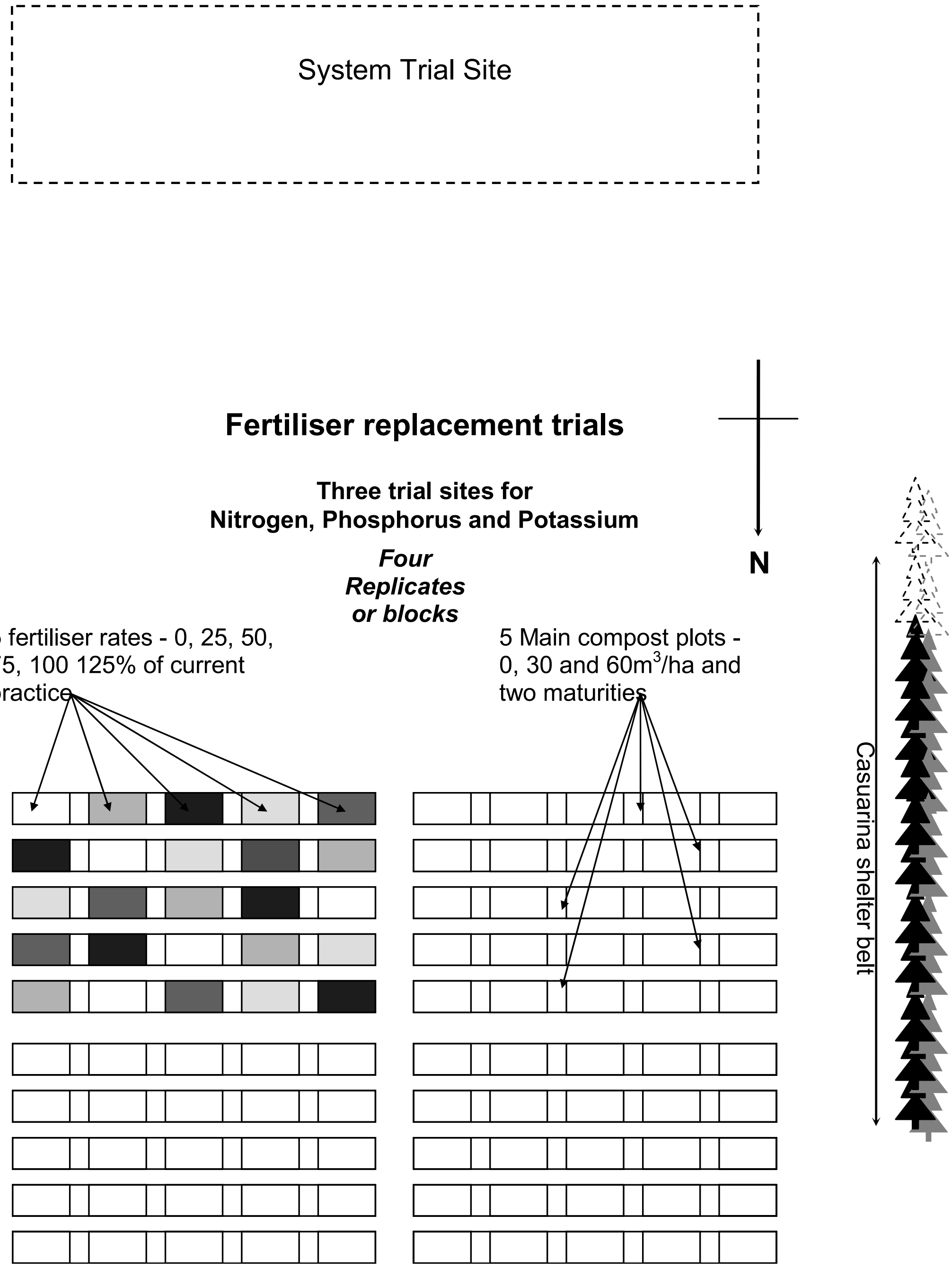


Diagram 1.2. Fertiliser replacement trial detail at the Medina Research Station (not to scale).

Nitrogen and potassium were applied as combinations of ammonium nitrate, ammonium sulphate and potassium nitrate, dissolved in water weekly throughout the life of the crop. Phosphatic fertiliser was applied as a single application of either single or double super phosphate immediately prior to planting the crop. Apart from the nutrient under investigation, fertiliser programs were based on best commercial practice. In addition to the three major nutrients, other major and minor nutrients were also applied in accordance with commercial practice.

All three sites were treated with Metham Sodium prior to the commencement of the trials and standard commercial weed and pest control practice was applied to all crops.

Lettuce was planted as seedlings at a spacing of 40 cm between rows and 30 cm between plants within rows. Each tray of 144 seedlings was drenched with 500 mL of a solution of 40 g/L of Potassium Nitrate prior to planting and all plots were sprayed with the same solution at a rate of 1000 litre/ha the day after transplanting and then every second day (3 times) prior to the first application of fertiliser treatments.

Carrots were seeded using an Agricola air seeder, 4 doubles per 1.2 m bed, to achieve a density of approximately 70 plants per square metre.

Measurements and harvest

For each plot a composite soil sample of 10, 32 mm auger holes to 15 cm, was analysed for nutrients at planting and harvest. Samples of 15–30 cm and 30–45 cm depth were collected at the commencement and completion of the trials on each site.

Youngest fully expanded leaf samples taken from each plot were analysed and the nutrient status of the plants at harvest determined.

For each plot a single sample of 12 lettuce plants was harvested to calculate crop production of lettuce mid growth and 2 samples of 12 whole plants were taken at final harvest. Whole plants were taken from the field, weighed and export heads removed. Two one metre lengths of the two inner double rows of carrots were harvested to calculate mid and final crop production of carrot crops. Carrots were washed and graded for quality into the categories: export marketable 150 long and 25–50 mm crown diameter; short marketable 120–150 long and 25–50 mm crown diameter; oversize > 50 mm crown diameter; forked; misshapen; split and underweight, to description level A, as described in “Carrot Product Description Language” Bulletin 4561 ISSN 1326-415X Department of Agriculture Western Australia.

Whole plant samples for nutrient balance calculations were taken at each harvest.

The volume of leachate collected in 45 drainage Lysimeters installed below strategic treatment plots was measured and sampled weekly. Irrigation and rain for these plots were recorded by rain gauge. Weekly samples were analysed separately for the first trial on each site only. Subsequently samples were bulked each fortnight or four weeks in proportion to volume collected and selected trials analysed.

At the nitrogen site, where the interested was in determining if compost reduced or increased the amount of nitrogen leached under normal fertiliser practice, lysimeters were located under 3 replications of the control plots with no applied Nitrogen and all main plot combinations at the 3rd level of applied Nitrogen. Lysimeters were also installed in plots treated with 60 m^3 of compost A and B with the highest level of applied Nitrogen.

At the phosphorus site lysimeters were installed under 3 replications of main plot combinations receiving no applied Phosphorus to determine the level of P leaching from the composts. The impact fertiliser P had on P leached from compost was measured on the Nitrogen site. The effect compost has on Potassium leaching was measured using leachate collected from the Nitrogen site. Lysimeters installed in the control plots on the Potassium site gave an estimate of the amount of K leached from the soil without compost or fertiliser.

Soil moisture was continuously monitored by tensiometers set at 15, 30 and 45 cm depth in a sub plot receiving the 4th highest level of the nutrient being tested for each main plot.

Soil bulk density, soil volumetric water content and soil strength was determined on two occasions on the site used to evaluate nitrogen and once during the demonstration trials.

Results were analysed using GENSTAT release 6 and 7 (split plot design with linear and quadratic contrasts and interactions for level of applied nitrogen).

Results – Nitrogen replacement trial site

Crop 1 - Lettuce

Iceberg lettuce seedlings, variety *Silverado*, were transplanted on 19 April 2001 and the following fertiliser treatments applied. The lettuce was harvested on 27 and 28 June (69 days). Intermediate growth was recorded on 15 May (25 days) and 5 June (46 days).

Treatment	Compost rates m^3/ha	Nitrogen rate kg N/ha	
Control	Nil	N1	Nil
A1/B1	30	N2	175
A2/B2	60	N3	285
		N4	395
		N5	510

Phosphorus (P) was applied at a rate of 200 kg of P per hectare together with a complete trace element mix as a single application across the site prior to planting. All treatments received 340 kg of Potassium and 28 kg of Magnesium per hectare. The Nitrogen treatments, together with Potassium and Magnesium were applied by watering can as 9 equal weekly applications.

Compost quality

Compost A failed to meet many of the criteria desired. The carbon to nitrogen ratio of 28 was high, it contained no plant available Nitrogen and the nitrogen drawdown index of 0.21 indicated it still contained readily available carbon. Although compost B had been heaped and stored for almost 9 months after its initial ‘thermophilic’ composting period it was similar to compost A. However, it’s carbon to nitrogen ratio, 21, was lower, it contained more than twice as much Phosphorus and the Nitrogen Drawdown index of 0.50 indicated it had acceptable low available Carbon (Appendix 1.1, Compost 1A & B).

Compost	Carbon Nitrogen Ratio	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 1A	28	0.21	55	1.3	< 1.0	< 0.1
Compost B	21	0.50	57	1.5	< 1.0	< 0.1

Fresh weight - 25 days

Analysis showed that control, and plots treated with different types of compost responded differently to applied nitrogen ($P < 0.01$). An exponential curve fitted to treatment means gave a probability of < 0.001 and accounted for 96.8 per cent of the variance (Figure 1.1). The relationship of total fresh weight of lettuce produced at harvest and nitrogen was described by the functions:

Control = $6.17 - 3.378\,(0.97965)^{\wedge Nitrogen}$
Compost A = $6.066 - 3.238\,(1.0)^{\wedge Nitrogen}$
Compost B = $7.086 - 3.415\,(0.98688)^{\wedge Nitrogen}$

While there was little response to applied nitrogen beyond 60 kg/ha there was a trend for plots treated with compost B to have higher fresh weights.

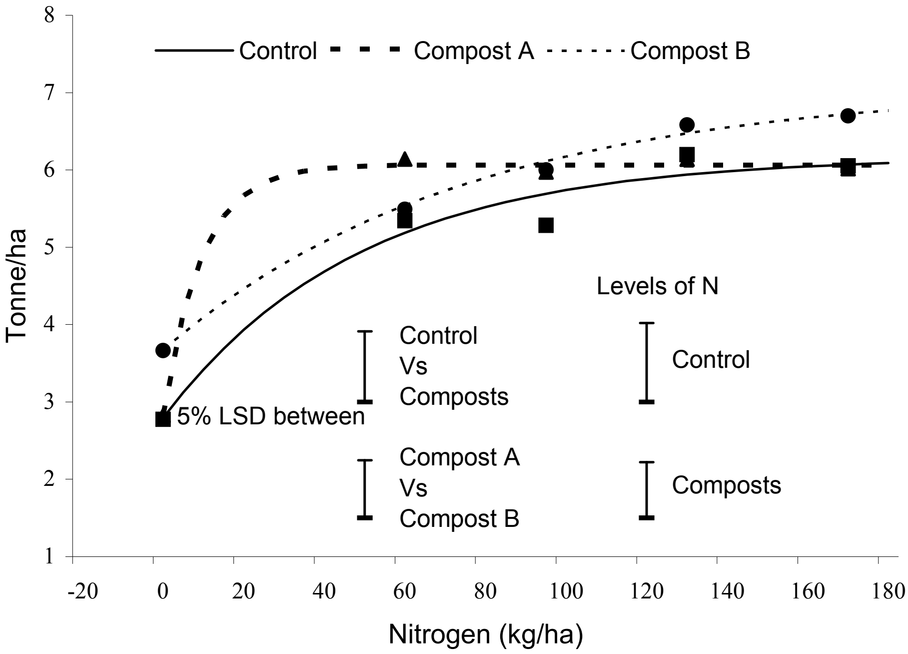


Figure 1.1. Fresh weight of lettuce harvested at day 25.

Plant analysis

Nitrogen

The linear relationship of concentration of nitrogen in whole plant tissue to applied nitrogen was different for control, and plots treated with different compost types ($P < 0.05$). Regression analysis revealed the relationship to be weak and generated by a relatively low concentration in compost A treated plots receiving no additional nitrogen and a relatively high concentration for compost A treated plots receiving the highest nitrogen application. With the exception of the nil application, all treatments exceeded levels considered adequate for lettuce (Table 1.1).

Table 1.1. Nitrogen in whole plant at 25 days (% db)

Treatment	Nitrogen application kg/ha				
	0	**58**	**95**	**132**	**170**
Control	2.59	3.68	3.48	3.65	3.81
Compost A	2.47	3.64	3.76	3.78	4.12
Compost B	2.79	3.65	3.96	3.59	3.77

lsd 5%	*Control vs Composts*	*0.50*
	Compost A v B	*0.41*
	Controls between Nitrogen	*0.62*
	Compost between Nitrogen	*0.44*

Phosphorus

The phosphorus content of whole plant showed a different quadratic response to level of applied nitrogen at each rate of compost ($P < 0.01$; Table 1.2). While differences between treatments were recorded and plots receiving zero nitrogen recorded lower values they were considered adequate and higher values for compost treated plots were consistent with the compost supplying additional Phosphorus.

Table 1.2. Phosphorus content of whole lettuce at 29 days (% db)

Treatment	Nitrogen application kg/ha				
	0	58	95	132	170
Control	0.49	0.65	0.60	0.61	0.67
30 m^3	0.51	0.61	0.62	0.62	0.69
60 m^3	0.50	0.64	0.67	0.64	0.64

lsd 5%	*Control vs Composts*	*0.067*
	Compost 30 m^3 v 60 m^3	*0.054*
	Controls between Nitrogen	*0.072*
	Compost 30 m^3 and 60 m^3 between Nitrogen	*0.051*

Potassium

Analysis showed that on average plots treated with compost had a higher Potassium concentration, i.e. 6.09 per cent compared to 4.8 per cent recorded for control plots ($P < 0.001$). Whole plant Potassium content for treated plots gave a different quadratic response to applied nitrogen than controls ($P < 0.01$). Exponential curves fitted to the treatment means ($P = 0.006$) accounted for 91.3 per cent of the observed variance (Figure 1.2). The concentration of Potassium in whole lettuce was described by the functions:

$$\text{Control} = 4.877 - 0.0039\,(1.0310)^{\text{Nitrogen}}$$
$$\text{Treated} = 6.399 - 0.929\,(0.9822)^{\text{Nitrogen}}$$

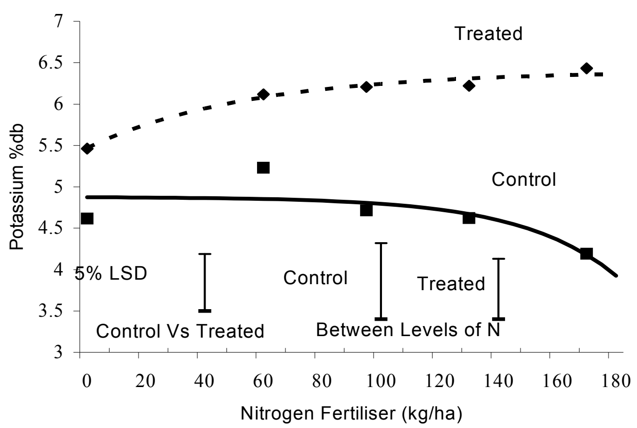


Figure 1.2. Potassium content of whole lettuce at 26 days.

Levels in the control treatment were lower than those required to achieve maximum yield in lettuce on the Potassium site (Table 1.184, Figure 1.31).

Plant uptake of nitrogen phosphorus and potassium

Total plant uptake of N and P was similar for all treatments and showed a quadratic response to applied Nitrogen (Table 1.3).

Table 1.3. Plant uptake of Nitrogen and Phosphorus 26 days (kg/ha)

Applied Nitrogen kg/ha	0	58	95	132	170
Nitrogen	6.33	14.40	15.07	15.88	17.05
Phosphorus	1.21	2.48	2.54	2.72	2.92

Uptake of K was higher for treated plots (23.43 kg/ha) compared to controls (17.5 kg/ha) ($P < 0.001$) and the amount of K taken up by plants showed a different linear response to applied nitrogen for control and treated plots ($P < 0.05$; Table 1.4).

Table 1.4. Plant uptake of Potassium (kg/ha) at 26 days

Treatment	Nitrogen application kg/ha				
	0	58	95	132	170
Control	10.35	19.21	18.87	20.36	18.70
Compost	13.28	24.38	24.59	26.84	28.07
lsd	*5% Control vs Compost*		*4.42*		
lsd	*5% Control between N levels*		*5.55*		
lsd	*5% Compost between N levels*		*2.77*		

Harvest - 45 days

On average plots treated with compost B yielded greater fresh weight, Table 1.5 ($P = 0.06$).

Table 1.5. Fresh weight of Lettuce at 45 days (t/ha)

Treatment	t/ha
Control	26.6 a*
Compost A	28.0 a
Compost B	29.1 b

* Values followed by a similar subscript are not different ($P > 0.06$).

Exponential curves fitted to plot data accounted for 94.8 per cent of the variance and showed plots treated with different compost responded differently to applied nitrogen ($P < 0.001$). The relationship of fresh weight of lettuce harvested at 69 days and applied nitrogen was described by the functions:

Control = $40.46 - 36.37\ (0.000428)^{\wedge Nitrogen}$
Compost A = $41.87 - 36.37\ (0.000428)^{\wedge Nitrogen}$
Compost B = $43.41 - 36.37\ (0.000428)^{\wedge Nitrogen}$

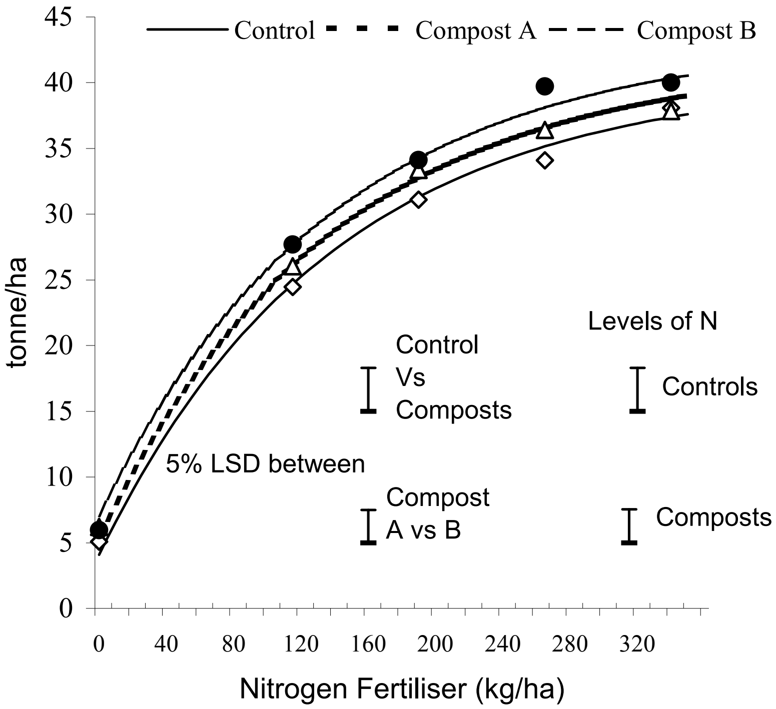


Figure 1.3. Fresh weight of lettuce harvested 45 days.

Final harvest - 69 days

Within the main plot stratum there was a significant effect of compost on total ($P < 0.05$) and market weight ($P < 0.001$) of lettuce and a quadratic response to applied nitrogen. The quadratic response of processed head weight to applied Nitrogen was different ($p < 0.05$) for control and treated plots. An exponential curve fitted to the plot data gave a probability of < 0.001 and accounted for 97.8 per cent of the variance (Figure 1.4). The relationship of processed head weight of lettuce produced at harvest and nitrogen was described by the functions:

Control = 79.17 – 73.35 $(0.991975)^{\wedge Nitrogen}$
Treated = 82.54 – 73.35 $(0.991975)^{\wedge Nitrogen}$

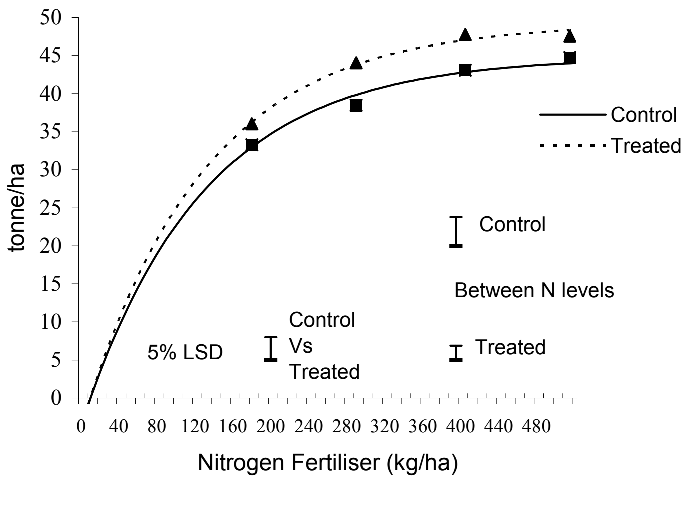


Figure 1.4. Weight of processed head of lettuce at 69 days (t/ha).

Percentage head

Compost increased the percentage head recovered from lettuce ($P < 0.01$) and different rates of compost gave a different linear response to applied nitrogen ($P < 0.05$; Table 1.6).

Table 1 6. Processed head as a percentage of the total plant harvested

Treatment	Nitrogen application kg/ha				
	10	180	290	405	515
Control	0	58.2	58.1	57.9	57.0
30 m^3	0	60.0	60.5	59.4	59.7
60 m^3	0	59.7	61.1	60.9	61.4

lsd 5%	*Control vs Composts*	*1.86*
	Compost 30 m^3 v 60 m^3	*1.52*
	Controls between Nitrogen	*1.95*
	Compost 30 m^3 and 60 m^3 between Nitrogen	*1.38*

Nitrogen, Phosphorus and Potassium content of whole plant

Nitrogen

While plant N content was similar within nitrogen applications, on average, plots treated with compost A gave lower N concentrations ($P < 0.05$) (Table 1.7).

Table 1.7. Nitrogen Concentration (% db) of whole plant

Treatment	Nitrogen application kg/ha					
	10	180	290	405	515	Average*
Control	1.08	2.48	3.04	3.75	3.84	2.84a
Compost A	0.98	2.42	2.94	3.40	3.60	2.67b
Compost B	1.04	2.45	3.01	3.45	3.70	2.79a

Phosphorus

Although analysis of variance showed a different quadratic response ($P < 0.05$) of plant P content to applied nitrogen for control and compost treated plots this was generated by a relatively high concentration recorded in control plots treated with 515 kg of nitrogen (Table 1.8). Recorded levels were within the expected range. An exponential curve fitted to the plot data accounted for only 39.5 per cent of the variance.

Table 1.8. Phosphorus content (% db) of whole lettuce at harvest

Treatment	Nitrogen application kg/ha				
	0	180	290	405	515
Control	0.405	0.488	0.478	0.518	0.645
Compost	0.418	0.506	0.519	0.548	0.538

lsd 5%	*Control vs Compost*	*0.072*
lsd 5%	*Control between N levels*	*0.093*
lsd 5%	*Compost between N levels*	*0.046*

Potassium

Within the main plot stratum the concentration of potassium in whole plant increased with rate of compost, i.e. the 4.98% recorded for control plots was less than the 5.48% recorded for plots treated with 30 cubic metres of compost which was less than the 5.80% recorded for plots treated with 60 cubic metres ($P < 0.05$). There was a different linear response

($P < 0.05$) for control and treated plots for potassium concentration in whole plant to increasing nitrogen application but the regression accounted for only 25 per cent of the variance (Table 1.9).

Table 1.9. Potassium content (% db) of whole lettuce at harvest

Treatment	Nitrogen application kg/ha				
	0	180	290	405	515
Control	3.995	5.942	4.982	5.137	4.817
Compost	3.907	6.174	6.251	6.274	5.60

lsd 5%	*Control vs Compost*	*0.684*
lsd 5%	*Control between N levels*	*0.870*
lsd 5%	*Compost between N levels*	*0.435*

Plant uptake of Nitrogen, Phosphorus and Potassium

Plant uptake of N, P, and K showed a quadratic response to applied nitrogen (Table 1.10).

Table 1.10. Plant uptake of Nitrogen, Phosphorus and Potassium (kg/ha)

Treatment	Nitrogen application kg/ha				
	0	180	290	405	515
Nitrogen	8.3	79.0	100.6	122.5	135.7
Phosphorus	3.3	16.2	16.7	18.7	20.2
Potassium	31.1	195.6	199.8	210.1	197.4

Nitrogen

Within the main plot stratum plants treated with compost absorbed more Nitrogen (92.9 kg/ha) than plants grown in control plots (89.4 kg/ha) $P < 0.01$. Plots treated with 60 m^3 of Compost A absorbed less Nitrogen than all other main treatments (Table 1.11; $P = 0.04$).

Table 1.11. Nitrogen uptake by lettuce top (kg/ha)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	89.4b*		
Compost A		90.5b	80.5a
Compost B		92.6b	93.1b

* Values followed by a common subscript are not different ($P > 0.05$).

Potassium

The linear response of plant uptake of Potassium to applied Nitrogen was different for plants grown in Control and Compost treated plots (Table 1.12; P < 0.05).

Table 1.12. Uptake of Potassium by whole lettuce at harvest (kg/ha)

Treatment	Nitrogen application kg/ha				
	0	180	290	405	515
Control	23.0	196.8	165.3	178.6	161.2
Compost	33.1	195.3	208.4	218.0	206.5
lsd 5%	*Control vs Compost*		*26.6*		
lsd 5%	*Control between N levels*		*35.7*		
lsd 5%	*Compost between N levels*		*17.8*		

Wrapper leaf analysis at harvest

Nitrogen

Nitrogen concentration of the youngest mature heart wrapper leaf at harvest was similar to whole plant (Table 1.13) and on average compost A recorded a lower concentration of N (P < 0.05). Nitrogen concentration increased with increasing level of applied N and plants receiving less than 290 kg of applied Nitrogen were below the critical deficient level.

Table 1.13. Nitrogen concentration of wrapper leaf (% db)

Treatment	Nitrogen application kg/ha					
	10	180	290	405	515	Average*
Control	1.11	2.25	2.83	3.34	3.59	2.624a
Compost A	0.95	2.32	2.86	3.25	3.49	2.573b
Compost B	1.01	2.42	3.00	3.43	3.60	2.693a
Average**	1.00	2.34	2.911	3.34	3.55	

* Values followed by a common subscript are not different (P > 0.05).
** lsd for average (P < 0.05) = 0.114.

Phosphorus

Phosphorus concentration of wrapper leaf was consistent with analysis of the whole plant with control plots receiving the highest rate of applied N recording a higher concentration of P (Table 1.14). Concentrations were in the normal range.

Table 1.14. Concentration of Phosphorus in wrapper leaf at harvest (% db)

Treatment	Nitrogen application kg/ha					
	0	180	290	405	515	Average
Control	0.455	0.422	0.452	0.432	0.550	0.462a*
Compost	0.419	0.434	0.429	0.432	0.455	0.434b
lsd 5%	*Control vs Compost*		*0.049*			
lsd 5%	*Control between N levels*		*0.060*			
lsd 5%	*Compost between N levels*		*0.030*			

Potassium

Potassium concentration of wrapper leaf was increased by compost and was lower at higher levels of applied N (Table 1.15). Zero applied N and control plots approached critical deficient levels.

Table 1.15. Potassium concentration of wrapper leaf (% db)

Treatment	Nitrogen application kg/ha				
	0	**180**	**290**	**405**	**515**
Control	4.88	5.94	5.09	4.96	4.70
Compost	4.39	6.61	6.49	6.13	5.79
lsd 5%	*Control vs Compost*		*0.69*		
lsd 5%	*Control between N levels*		*0.87*		
lsd 5%	*Compost between N levels*		*0.43*		

Other minerals

Concentration of other mineral are shown in Table 1.16. Concentration of copper was low and calcium and sulphur were marginal.

Table 1.16. Analysis of wrapper leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range**
% db				
Sodium	0.72	0.64	0.07	< 0.5–1.0
Calcium	0.92	0.92	ns	1.4–2.0
Magnesium	0.35	0.32	0.02	0.3–0.7
Sulphur	0.21	0.20	ns	0.3–0.32
mg/kg				
Boron	21	22	ns	25–55
Copper	3.4	3.5	ns	10–18
Iron	408	425	ns	50–500
Manganese	44	43	ns	50–300
Molybdenum	2	2	ns	0.08–0.17
Zinc	33	28	5	30–100

* lsd - least significant difference P = 0.05.

** Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.

Soil analysis at planting

Carbon

Compost application increased soil carbon in the top 15 cm from 0.59 to 0.79 per cent ($P < 0.001$). The difference between rate of Compost applied, 30 m^3, (0.76% carbon) and 60 m^3, (0.82%) did not quite reach significance ($P = 0.09$).

Total Nitrogen, Nitrogen as Ammonia and Nitrate

0–15 cm depth

Compost increased total soil nitrogen in the top 15 cm, compost B, (0.044%) recorded higher levels than A (0.038%), and both were higher than the control plots (0.026%) ($P < 0.05$). Levels of plant available Nitrogen present as Ammonium (1.66 mg/kg) and Nitrate (3.29 mg/kg) were low and there was no difference between treatments.

15–30 cm depth

The influence of the compost application had moved marginally below the 15 cm level and treated plots (0.32%) had higher total N levels than control plots (0.26%) ($P < 0.01$). Nitrogen present as Ammonium (1.9 mg/kg) and Nitrate (4.8 mg/kg) was similar for all plots.

Soil analysis at harvest

0–15 cm depth

Carbon

The linear trend for soil carbon in compost treated plots to decline with increasing application of Nitrogen was different to the trend for carbon in control plots to increase with increased application of Nitrogen ($P < 0.05$; Table 1.17).

Table 1.17. Carbon content of soil (0-15 cm) at harvest (% db)

Treatment	Nitrogen application kg/ha				
	0	180	290	405	515
Control	0.52	0.55	0.58	0.56	0.67
Compost	0.74	0.75	0.73	0.68	0.67
lsd 5%	*Control vs Compost*		*0.13*		
lsd 5%	*Control between N levels*		*0.16*		
lsd 5%	*Compost between N levels*		*0.08*		

Total nitrogen

Compost increased total Nitrogen and soil nitrogen for control and compost treated plots responded differently to applied nitrogen ($p < 0.05$; Table 18).

Nitrogen as Ammonium

Levels of Nitrogen as ammonium averaged less than 1 mg/kg for all treatment combinations.

Table 1.18. Total Nitrogen content of soil (0–15 cm) at harvest (% db)

Treatment	Nitrogen application kg/ha				
	0	180	290	405	515
Control	0.025	0.027	0.026	0.028	0.036
Compost	0.035	0.036	0.036	0.034	0.035
lsd 5%	*Control vs Compost*		*0.0059*		
lsd 5%	*Control between N levels*		*0.0070*		
lsd 5%	*Compost between N levels*		*0.0035*		

Nitrogen as nitrate

Within main plots the level of Nitrogen present as nitrate in plots treated with 60 m^3 of compost (6.12 mg/kg) was lower than plots treated with 30 m^3 (7.63 mg/kg) and control plots (8.00 mg/kg) ($P < 0.05$). The response of soil nitrate to applied Nitrogen was different for each rate of compost ($P < 0.01$; Table1.19).

Table 1.19. Soil content of Nitrogen as Nitrate 0–15 cm at harvest (mg/kg db)

Treatment		Nitrogen application kg/ha				
		10	180	290	405	515
Control		1.75	3.25	6.75	11.50	16.75
Compost A		1.10	1.75	3.75	8.75	16.50
Compost B		1.12	1.87	5.50	9.88	18.5
lsd 5%	*Control vs Composts*			*3.45*		
	Compost A v B			*2.72*		
	Controls between Nitrogen			*3.86*		
	Compost between Nitrogen			*2.73*		

Nutrient leaching

The quantity of nutrients leaching into the drainage lysimeters was directly influenced by the amount of irrigation and rain falling on the plots. Growing conditions were typical for Autumn–Winter with rainfall and irrigation exceeding plant requirements for most weeks (Figure 1.5).

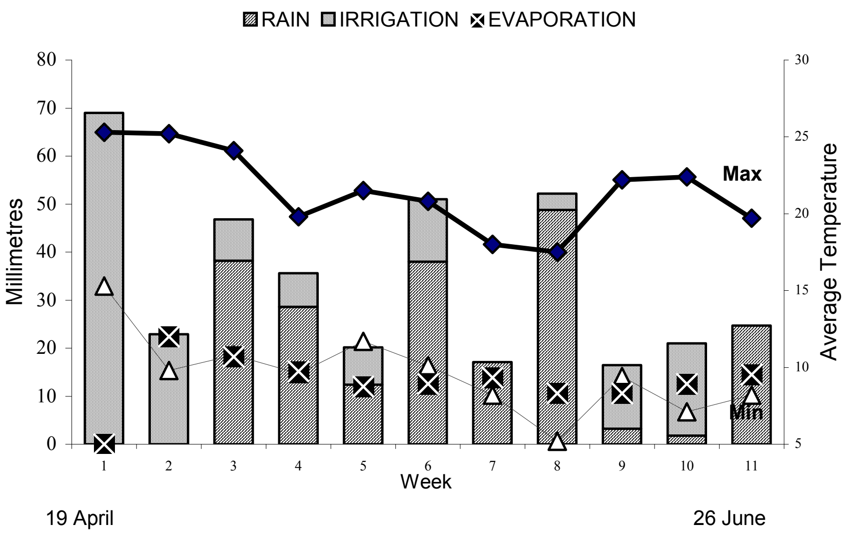


Figure 1.5. Weather conditions for lettuce crop 1.

All treatments leached a similar amount of water with 58% (195 mm) of the rain (221 mm) and irrigation (116 mm) being collected in the drainage lysimeters. Evaporation was 177 mm and the apparent crop water use (rain + irrigation – drainage) was 142 mm or 80 per cent of evaporation.

Nutrients leached

Nutrients collected in the drainage lysimeters positioned under selected treatments are shown in Table 1.20.

Table 1.20. Nitrogen and Potassium collected in drainage lysimeters during crop growth

Compost	Rate m^3/ha	Applied Nitrogen kg/ha	Total Nitrogen kg/ha	N as NH_4 kg/ha	N as NO_3 kg/ha	Organic N kg/ha*	Potassium leached kg/ha
Control	0	0	67.9a	2.0	38.1a	27.8a	
Control	0	285	105.3a	3.4	54.1a	47.8a	29.5
A	30	285	85.5a	0.8	43.8a	40.9a	21.9
B	30	285	100.7a	1.9	56.3a	42.4a	31.0
A	60	285	98.1a	3.7	51.2a	43.1a	40.7
B	60	285	97.6a	2.3	55.9a	39.5a	33.1
A	60	515	175.6b	2.5	100.2b	72.9b	
B	60	515	212.8b	0.8	137.6b	75.4b	

* Values followed by a common subscript are not different ($P > 0.05$). Values are the mean of 3 replicates

Nitrogen

The application of 285 kg fertiliser nitrogen to control plots increased the total amount of nitrogen collected in the lysimeters from the equivalent of 68 to 105 kg/ha ($P = 0.065$). Compost and compost rate did not increase the amount of Nitrogen leached from plots treated with 285 kg of fertiliser nitrogen and on average 97 kg/ha was leached. Nitrogen leaching from plots spread with 60 cubic metres of compost was increased by the application of 515 kg of fertiliser when compared to plots receiving 285 kg of fertiliser Nitrogen (194 versus 98 kg/ha) ($P < 0.001$). The increase being made up of 66 kg of Nitrogen as nitrate and 30 kg of dissolved organic nitrogen.

Organic nitrogen represented a significant portion of the total amount of nitrogen leached.

The leaching of nitrogen as Ammonium from all treatments was low and averaged 2 kg/ha.

Phosphorus and Potassium

All plots received 200 kg of Phosphorus and 340 kg of Potassium fertiliser. No Soluble reactive Phosphorus was recovered from the leachate (< 0.01 mg/l) but a small amount of total Phosphorus, in concentrations of > 0.1 mg/L, were recorded. There was a trend for the matured compost to leach less total Phosphorus ($P = 0.10$; Table 1.21).

Table 1.21. Total Phosphorus leached (kg/ha)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	0.213		
Compost A		0.207	0.194
Compost B		0.093	0.095

Compost type and rate had no effect on the amount of Potassium leached and an average of 31 kg/ha was recovered from lysimeters under main plots receiving 285 kg of applied Nitrogen fertiliser (Table 1.20).

Discussion

While neither compost met the quality criteria considered necessary for a positive plant response Compost B was arguable better than Compost A and showed better growth at 25 and 45 days (Figures 1.1 and 1.3). Chemical analysis at 26 days suggested that the observed plant responses were the result of better Potassium and Phosphorus status in plants grown in compost treated plots rather than nitrogen (Tables 1.1, 1.2 and Figure 1.2). This was consistent with Compost B containing more Potassium and Phosphorus (Appendix 1.1 A1,B). Growth differences between composts were not evident at the final harvest but within main plots compost treated plots produced more fresh weight and more processed head (Figure 1.4) because of a higher percentage of head (Table 1.9).

Compost A reduced plant nitrogen content (Table 1.10) and when applied at 60 m^3/ha resulted in lower plant uptake of nitrogen (Table 1.11). The lower nitrogen status of plants coming from plots treated with compost A was confirmed by analysis of the youngest mature wrapper leaf (Table 1.13).

Chemical analysis of whole plant and youngest fully mature wrapper leaf at harvest showed concentrations of Potassium in plants from Control plots approached the critical deficient level at the higher rates of applied Nitrogen. A growth response to the additional Potassium supplied by the compost is therefore the most likely explanation for the plant response recorded.

Compost increased soil carbon and nitrogen at planting and harvest. There was an indication that compost increased demineralisation of fertiliser nitrate and caused lower concentrations of soil nitrate at harvest (Table 1.19).

Compost did not increase the leaching of nutrients.

Crop 2 - Carrot

The following compost treatments were applied and incorporated into the soil together with an application of 200 kg per hectare of phosphorus and trace minerals one week prior to seeding carrots, variety *Stefano*, on 26 July 2001.

Treatment	Compost rates m^3/ha	Nitrogen rate kg N/ha	
Control	Nil	N1	Nil
A1/B1	30	N2	155
A2/B2	60	N3	233
		N4	310
		N5	388

Nitrogen treatments were applied as potassium nitrate and sulphate of ammonia weekly by watering can together with a total of 290 kg/ha of potassium, 19.5 kg of magnesium and 2 kg of Boron. The amount applied weekly was adjusted as a percentage of the total growth expected over 145 days with fertiliser application ceasing 2 weeks before harvest (A. Galati and A. McKay, Carrot Yield Decline, Horticulture Research and Development Corporation Final Report Project VG27). The carrots grew well and were harvested 2 weeks before schedule at 131 days on 4 December. Intermediate harvest yields were recorded on 9 October (75 days) and 13 November (119 days).

Compost quality

The fresh compost supplied was coarse and woody and met few of the criteria considered necessary to record a positive crop response but did contain a low level of plant available nitrate nitrogen. With the exception of reduced seedling toxicity, the chemical analysis of compost B1 had changed very little over the 12 week period during which it had been kept moist and turned twice (Appendix 1.1, Compost A2 and B1).

Compost	Carbon Nitrogen Ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 2A	31.0	0.34	98	1.3	23	23.00
Compost B1	28.0	0.26	95	1.4	< 1.0	< 0.1

Germination

Compost reduced germination at 16 days from 57 plants/m^2 for control plots to 53 for plots receiving compost ($P = 0.027$). However, plant density at the first harvest on day 75 averaged 60 plants/m^2 with a trend for 60 m^3 of compost to reduce plant density when compared to an application of 30 m^2 ($P = 0.062$; Table 1.22).

Table 1.22. Plant density at 75 days (plants/m^2)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	59.13		
Compost		62.24	58.77

Harvest - 75 days

Within the main plot stratum compost reduced plant growth and 60 m^3 of compost A gave lower growth when compared to other compost and control treatments ($P < 0.001$; Table 1.23).

Table 1.23. Total plant (tonne/ha)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	14.19a*		
Compost A		11.97bc	9.80d
Compost B		12.41b	11.23c

* Values followed by a common subscript are not different ($P > 0.05$).

Compost treated plots gave a different linear response to nitrogen when compared to control plots ($P < 0.05$) (Figure 1.5).

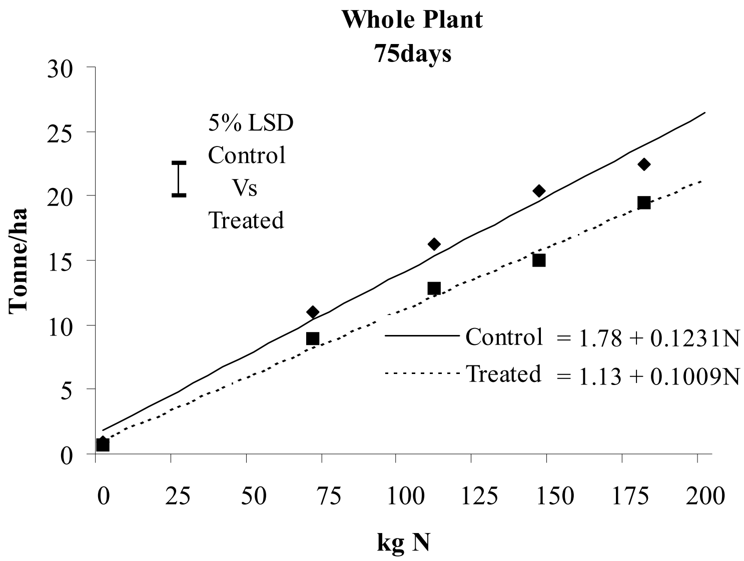


Figure 1.5. Total carrot plant weight at day 75.

Differences in total plant weight were the result of differences in plant top weight rather than roots and on average the root to shoot ratio of compost treated plots (1.29) was higher than for control plots (1.14) (P < 0.01). The linear response of Top growth to applied nitrogen was different for control and compost treated plots (P < 0.01; Table 1.24).

Table 1.24. Weight of carrot top at 75 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	72	108	144	180
Control	0.59	4.69	6.68	8.99	10.31
Compost	0.41	3.46	4.96	6.09	8.28
lsd 5%	*Control vs Compost*		*1.08*		
lsd 5%	*Control between N levels*		*1.48*		
lsd 5%	*Compost between N levels*		*0.74*		

Harvest - 119 days

Plant density

Plant density declined with the level of applied nitrogen and control and treated plots responded differently to applied N with control plots showing reduced plant numbers at the highest application of Nitrogen (P < 0.05; Table 1.25).

Table 1.25. Plant density (plants/m^{2})

Treatment	Nitrogen application kg/ha				
	0	126	190	253	316
Control	68.0	69.6	62.3	60.7	50.7
Compost	64.8	63.7	61.1	61.1	60.2
lsd 5%	*Control vs Compost*		*8.3*		
lsd 5%	*Control between N levels*		*7.5*		
lsd 5%	*Compost between N levels*		*5.0*		

Plant weight

Control and treated plots showed a different quadratic response to applied nitrogen for total plant weight ($P < 0.001$; Table 1.26), weight of top ($P < 0.05$; Table 1.27) and weight of root ($P < 0.001$; Table 1.28). These showed that the application of compost had reduced both top and root growth at rates of applied nitrogen lower than 180 kg/ha.

Table 1.26. Total plant weight of carrots at 119 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	**126**	**190**	**253**	**316**
Control	8.24	57.66	71.12	79.96	78.12
Compost	7.71	46.43	60.05	72.61	81.76
lsd 5% Control vs Compost			*7.66*		
lsd 5% Control between N levels			*8.91*		
lsd 5% Compost between N levels			*4.45*		

Table 1.27. Weight of carrot top at 119 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	**126**	**190**	**253**	**316**
Control	1.61	8.10	10.72	13.74	14.80
Compost	1.62	6.63	9.00	11.60	14.83
lsd 5% Control vs Compost			*1.54*		
lsd 5% Control between N levels			*1.80*		
lsd 5% Compost between N levels			*1.42*		

Table 1.28. Weight of carrot root at 119 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	**126**	**190**	**253**	**316**
Control	6.63	49.56	60.39	66.23	63.33
Compost	6.09	39.81	51.05	61.01	66.93
lsd 5% Control vs Compost			*6.3*		
lsd 5% Control between N levels			*7.39*		
lsd 5% Compost between N levels			*3.69*		

An exponential curve fitted to the plot data for total plant gave a probability of < 0.001 and accounted for 91.4 per cent of the variance (Figure 1.6). The relationship of total weight of carrots produced at harvest 2 and nitrogen was described by the functions:

Control = $86.02 - 77.96\,(0.99158)^{nitrogen}$
Treatment = $126.1 - 118.3\,(0.996891)^{nitrogen}$

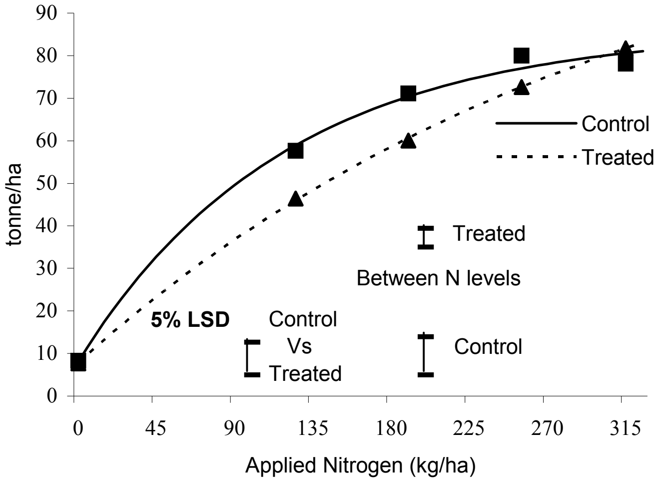


Figure 1.6. Total plant growth of carrots at 119 days.

Final harvest - 131 days

Plant density

Within main effects less carrots (56/sq m) were harvested from compost treated plots than from Control plots (62/sq m).

Whole plant weight

Within the main plot stratum compost reduced whole plant growth ($P < 0.01$), higher rates caused greater reduction ($P < 0.01$) and the linear response of whole plant growth to applied nitrogen was different for control and compost treated plots ($P < 0.001$; Table 1.29). There was no effect of compost type.

Table 1.29. Total plant weight of carrots at 131 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	155	233	310	388
Control	18.05	93.47	106.89	137.14	150.84
Compost	20.37	80.91	95.62	118.64	126.66
lsd 5%	*Control vs Compost*		*11.3*		
lsd 5%	*Control between N levels*		*10.4*		
lsd 5%	*Compost between N levels*		*6.6*		

Weight of top

Within the main plot stratum compost reduced weight of top ($P < 0.01$), higher rates caused greater reduction ($P < 0.05$) and the linear response of top growth to applied nitrogen was different for control and compost treated plots ($P < 0.001$; Table 1.30). There was no effect of compost type.

Table 1.30. Weight of carrot top at 131 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	155	233	310	388
Control	2.09	10.28	12.70	18.99	23.11
Compost	2.47	9.08	11.63	15.58	18.97

lsd 5%	*Control vs Compost*	*2.05*
lsd 5%	*Control between N levels*	*2.49*
lsd 5%	*Compost between N levels*	*1.24*

Weight of carrot root

Within the main plot stratum compost reduced the weight of roots produced (control, 87.8 tonne/ha and treated plots 76.9 ($P < 0.002$)). Higher rates of application caused greater reduction ($P < 0.001$) and the response of total root weight to applied nitrogen was different for control and compost treated plots ($P < 0.001$).

An exponential curve fitted to the plot data for total root weight and grouped for rate of compost applied gave a probability of < 0.001 and accounted for 93.2 per cent of the variance (Figure 1.7). The relationship of total weight of carrots produced at 131 days and applied nitrogen was described by the functions:

Control = $160.6 - 144.5\,(0.996242)^{nitrogen}$
30 cubic metres = $142.6 - 120.7\,(0.996242)^{nitrogen}$
60 cubic metres = $130.5 - 116.3\,(0.996242)^{nitrogen}$

The application of compost reduced crop yield and more nitrogen was required to achieve equivalent yields. The functions predict that a typical commercial yield of 100 tonne/ha of carrots would be achieved by the application of 240 kg of nitrogen/ha on control plots, 280 kg/ha on plots treated with 30 cubic metres of compost and 360 kg/ha when 60 cubic metres of compost was used. The increased nitrogen requirement associated with the application of the compost is consistent with the high carbon/nitrogen ratio of the products used.

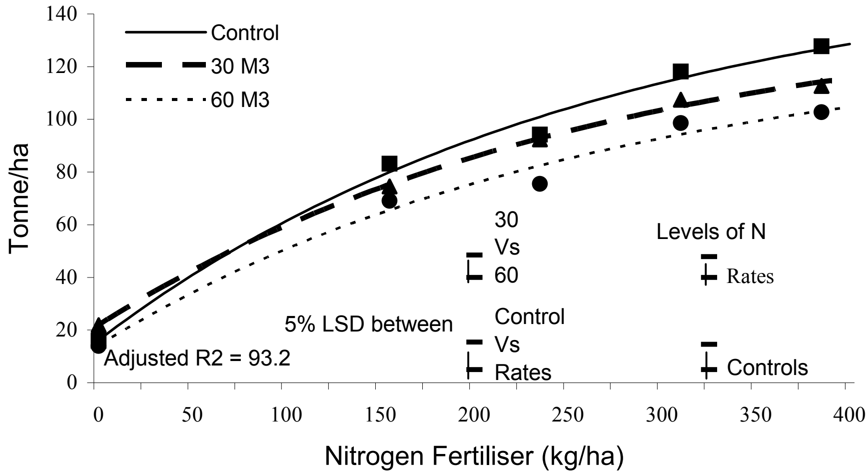


Figure 1.7. Response of final carrot harvest weight to applied nitrogen and Compost Rate.

Marketable carrots

There was a trend for compost treated plots to record less reject carrots and the differences in marketable yield (control 57 and treated 53 tonne/ha) were not significant.

Nutrient content of top and root

The concentration of nitrogen in top and root were significantly affected by the rate of compost applied. Compost at 30 m^3 recorded higher levels of nitrogen in roots than control and 60 m^3 but lower leaf concentrations than compost at 60 m^3. Phosphorus concentration was similar for all treatments but compost increased potassium concentration (Table 1.31).

Table 1.31. Nutrient content of carrot leaves and roots at harvest (% db)

Nutrient	Carrot	Control	30 m^3	60 m^3
N nitrogen	Top	1.827ab	1.796b	1.879a
	Root	1.024b	1.087a	1.032b
P phosphorus	Top	0.376	0.377	0.365
	Root	0.384	0.398	0.392
K potassium	Top	2.255b	2.823a	2.896a
	Root	2.117c	2.478b	2.581a

* Values in rows followed by a common subscript are not different (P > 0.05).

Leaf analysis, youngest fully matured leaves

Compost increased potassium and calcium concentration and decreased sodium, boron, iron, manganese and zinc concentrations. Despite two applications of trace elements concentrations of copper and manganese where below the normal range (Table 1.32).

Table 1.32. Analysis of youngest fully matured carrot leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range*
% db				
Phosphorus	0.32	0.32	ns	0.3–0.4
Potassium	2.43	2.99	0.16	1.3–1.5
Sodium	1.48	1.08	0.08	0.7–4.5
Calcium	3.47	3.67	0.16	1.8–2
Magnesium	0.40	0.40	ns	0.35–0.40
Sulphur	0.30	0.30	ns	0.3–0.6
mg/kg				
Boron	43.2	40.5	1.0	29–35
Copper	3.46	3.35	ns	5–7
Iron	2065	1836	150	120–350
Manganese	109	61	11	190–350
Zinc	33.2	25.6	2.5	20–50

* Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.

Soil analysis at planting

Soil carbon

Within main plots soil organic carbon content increased with rate of compost application; control 0.57; 30 m^3 0.75; 60 m^3 0.80 (% db) ($P = 0.07$) and the linear response of soil carbon to applied nitrogen was different for control and compost treated plots ($P < 0.05$). There was a trend for higher rates of Nitrogen application to increase the retention of carbon in control plots and reduce the retention of carbon in compost treated plots ($P < 0.05$; Table 1.33).

Table 1.33. Organic carbon content of soil at planting (% db)

Treatment	Nitrogen application kg/ha				
	16	155	233	310	388
Control	0.52	0.56	0.58	0.56	0.62
Compost	0.81	0.80	0.77	0.74	0.73
lsd 5%	*Control vs Composts*		*0.13*		
	Controls between Nitrogen		*0.16*		
	Compost between Nitrogen		*0.08*		

Nitrogen

Within the main plot stratum soil nitrogen increased with application of compost (Table 1.34).

Table 1.34. Soil nitrogen at planting (% db)

Treatment	%
Control	0.028a*
30 m^3	0.040b
60 m^3	0.044c

* Values followed by a different subscript are different ($P < 0.05$).

Nitrogen as nitrate

While nitrate levels were modest compost type rather than rate affected the level of soil nitrogen present as nitrate ($P < 0.001$; Table 1.35).

Table 1.35. Soil Nitrogen as nitrate at planting (mg/kg db)

Treatment	mg/kg
Control	2.45a*
Compost A	3.96b
Compost B	2.70a

* Values followed by a common subscript are not different ($P > 0.05$).

Nitrogen present as Ammonium

Levels of soil Nitrogen present as ammonium were low. Higher levels were recorded in plots treated with 30 m^3 of compost ($P < 0.05$; Table 1.36).

Table 1.36. Soil Nitrogen as ammonium at planting (mg/kg db)

Treatment	mg/kg
Control	1.400a*
30 m^3	1.700b
60 m^3	1.175a

* Values followed by a common subscript are not different (P > 0.05).

Soil carbon and Nitrogen at harvest

Soil carbon

Soil carbon altered little over the cropping period and the trend for higher rates of Nitrogen application to increase the retention of carbon in control plots and reduce the retention of carbon in compost treated plots remained (P < 0.05; Table 1.37).

Table 1.37. Organic carbon content of soil at harvest (% db)

Treatment	Nitrogen application kg/ha				
	16	155	233	310	388
Control	0.55	0.53	0.56	0.58	0.66
Compost	0.80	0.79	0.75	0.72	0.71
lsd 5%	*Control vs Composts*		*0.14*		
	Controls between Nitrogen		*0.18*		
	Compost between Nitrogen		*0.09*		

Soil Total Nitrogen was similar to that recorded at planting. Control plots averaged 0.03% db and Treated plots 0.043% (P < 0.001). Differences between Compost A and B had disappeared.

Nitrogen present in the nitrate form had declined and controls measured 1.30 and treated plots 1.90 mg/kg db (P = 0.04).

Nitrogen present as ammonium was similar to that recorded at harvest with controls averaging 1.040 and treated plots 1.473 mg/kg (P = 0.006).

Growing conditions

Crop management was good but irrigation over the final two weeks of the growing period fell 12 mm below recommendations (Figure 1.8).

Nutrient leaching

All treatments measured leached a similar amount of water with 51% (471 mm) of the rain (226 mm) and irrigation (703 mm) being collected in the drainage lysimeters. Evaporation was 566 mm and the apparent crop water use (rain + irrigation – drainage) was 458 mm or 81 per cent of evaporation.

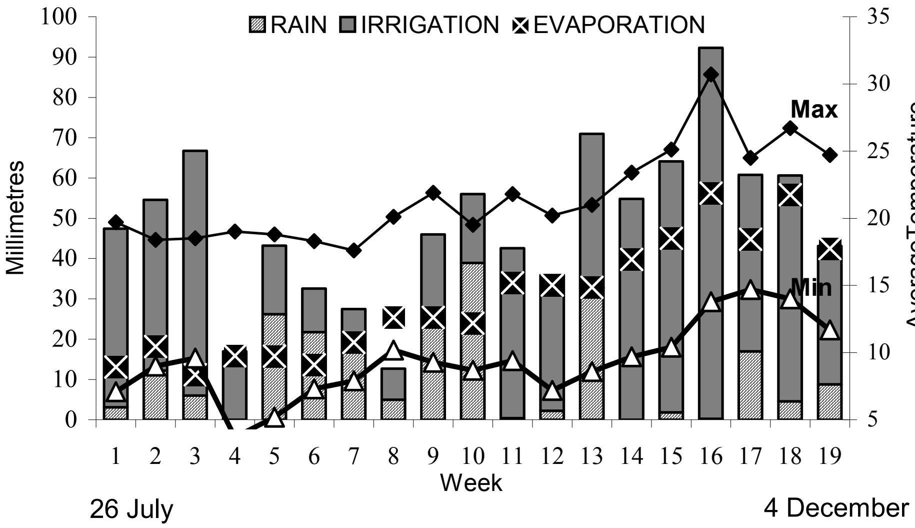


Figure 1.8. Weather conditions carrot crop 2.

Nutrients recovered from drainage lysimeters installed under selected treatments are shown in Table 1.38.

Separate analysis of plots treated with 60 m^3 of compost confirmed an interaction between compost type and applied nitrogen and compost B leached more nitrogen than compost A when 450 kg of fertiliser nitrogen was applied (P = 0.04).

Analysis of plots treated with 250 kg of applied nitrogen showed that on average plots spread with 60 m^3 of compost leached 28.7 kg/ha of organic nitrogen and control and plots spread with 30 m^3, 4.8 and 12.8 kg/ha respectively (P = 0.047).

All plots received 200 kg of Phosphorus before the carrots were seeded and 290 kg of Potassium was applied during the growing period.

No Soluble Reactive Phosphorus was measured (< 0.01 mg/L) and only 4 samples recorded levels of total Phosphorus at the level of detection of 0.1 mg/L. This level of detection allows us to say that less than 500 mg/ha of Phosphorus was leached during the 19 week cropping period.

Table 1.38. Nitrogen collected in drainage lysimeters during crop growth

Compost	Rate m^3/ha	Applied Nitrogen kg/ha	Total Nitrogen kg/ha	N as NH_4 kg/ha	N as NO_3 kg/ha	Organic N kg/ha	Potassium leached kg/ha
Control	0	0	27.5a	1.8	19.7a	6.0	
Control	0	250	101.6b	5.3	91.4b	4.8	59.1
A	30	250	87.4b	1.2	76.0b	10.2	73.1
B	30	250	106.9b	3.5	88.0b	15.4	86.5
A	60	250	107.0b	6.3	67.1b	33.6	134.5
B	60	250	118.6b	3.4	91.5b	23.8	118.1
A	60	450	155.2c	0.7	142.4c	12.1	
B	60	450	245.8d	1.3	216.8d	27.7	

* Values followed by a common subscript are not different (P> 0.05). Values are the mean of 3 replicates.

The equivalent of approximately 20 per cent of the applied Potassium leached from control plots. Much of the additional Potassium supplied by the compost also leached and on average plots spread with 60 m^3 of compost leached more Potassium (P = 0.036).

Discussion

This second batch of compost, A2 Appendix 1.1, did not meet specifications and was similar to the first batch, A1. However, it contained 23 mg/L of nitrate nitrogen which was reflected in a slightly higher soil nitrate level at planting for plots spread with this compost (Table 1.34). Despite this Compost A recorded the lowest plant production at 75 days (Table 1.23).

On average compost also reduced plant density and this was measured to be 10 per cent lower for compost treated plots at the final harvest.

Harvest at 119 days suggested that the growth depression caused by the compost was eliminated at the highest nitrogen application rate of 316 kg/ha (Figure 1.6). However, the final harvest which was delayed slightly beyond optimum date, showed compost reduced the weight of carrot top and root even at high rates of nitrogen application (Table 1.30, Figure 1.7).

Variation between plots and a trend for carrots from compost treated plots to yield a higher percentage of market A, B grade carrots meant no difference between treatments in marketable yield was recorded.

The reduction in total yield could not be explained by lower nitrogen nutrient status in carrot leaves and roots (Table 1.31) and there was a trend for compost to increase nitrogen content. This was consistent with the better soil nitrogen status of the composted soil recorded at seeding and harvests (Tables 1.34 and 35).

The additional Potassium supplied by the compost was readily taken up by carrot top and root (Table 1.31). Compost reduced leaf concentrations of manganese and zinc (Table 1.32).

While compost did not increase the total amount of nitrogen leached the amount of organic nitrogen leached increased with rate of compost applied and represented 30 per cent of the total leached in plots treated with 60 m^3 of compost A (Table 1.38).

Soil carbon continued to build with application of compost but there was a trend for levels to decline with increased application of nitrogen. This was consistent with increased nitrogen increasing microbial activity and burning carbon. The higher return of crop residue into the soil with increased nitrogen application caused a reverse trend in control plots (Table 1.37).

Results show that carrot production is sensitive to compost quality and composts with similar analysis to the samples used in this trial could be expected to reduce total carrot yield.

Lettuce - Crop 3

Iceberg lettuce seedlings, variety *magnum*, were transplanted on 24 January 2002 and the following fertiliser treatments applied weekly by watering can for 5 weeks. The lettuce was harvested 41 days later on 6 March 2002. Intermediate growth was recorded on 13 February (20 days).

Treatment	Compost rates m^3/ha	Nitrogen rate kg N/ha	
Control	Nil	N1	Nil
A1/B1	30	N2	175
A2/B2	60	N3	285
		N4	395
		N5	510

Phosphorus was applied at a rate of 200 kg of P per hectare together with a complete trace element mix as a single application across the site prior to planting. All treatments received 450 kg of Potassium and 25 kg of Magnesium per hectare. The Nitrogen treatments, together with Potassium and Magnesium were applied by watering can as weekly applications. Weekly amounts were apportioned; week 1, 10%; week 2, 20%; week 3, 30%; week 4, 30% and week 5, 10 per cent of the total fertiliser applied.

Compost quality

Compost A contained a low level of plant available Nitrogen (89 mg/L as nitrate), the Nitrogen Draw Down index (0.44) and Toxicity (100) indicated it was relatively stable and the C/N ratio was less than 20. Compost B, which had been compost A (A2 Appendix 1.1) for the previous carrot crop, had composted further and its analysis had improved in respect to the criteria desired (Appendix 1.1 Compost A4 and 2B).

Compost	Carbon Nitrogen Ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 4A	19	0.54	81	1.6	89	< 0.1
Compost 2B	21	0.45	91	1.6	< 1.0	< 0.1

Harvest - 20 days

While analysis showed no significant differences between treatments the probability that the linear response of control and compost treated plots to applied nitrogen was different was 0.074 and there was a trend for compost to give higher plant weight (Table 1.39).

Table 1.39. Weight of lettuce plants at day 20 (g)

Treatment	Nitrogen application kg/ha				
	16	45	75	105	135
Control	93	142	124	140	144
Compost	81	138	149	158	156

Final harvest - 41 days

The linear response of total plant weight to applied nitrogen for compost treated and control plots was different (P = 0.035) and there was an interaction between compost and applied nitrogen (P = 0.05; Table 1.40).

Table 1.40. Weight of lettuce plants at day 41 (t/ha)

Treatment	Nitrogen application kg/ha				
	16	150	250	350	450
Control	11.4	58.8	65.9	66.0	67.0
Compost	12.7	55.9	68.7	75.5	72.3
lsd 5%	*Control vs Composts*		*6.7*		
	Controls between Nitrogen		*7.3*		
	Compost between Nitrogen		*3.7*		

Weight of processed head

The response of processed head weight to compost and applied Nitrogen was similar to that recorded for Total Plant Weight but plants from plots treated with compost A recorded higher percentage head (Table 1.41).

Table 1.41. Percentage lettuce head weight

Treatment	% Head weight*
Control	52.6a
Compost A	55.7b
Compost B	53.0a

* Values followed by a common subscript are not different (P > 0.05).

An exponential curve fitted to the plot data for Fresh Weight of Lettuce gave a probability of < 0.001 and accounted for 93.4 per cent of the variance (Figure 1.8). The relationship of weight of lettuce produced at harvest and nitrogen was described by the functions:

Control = 67.07 – 70.08 (0.98569)$^{\wedge Nitrogen}$
Treated = 75.99 – 73.25 (0.991086)$^{\wedge Nitrogen}$

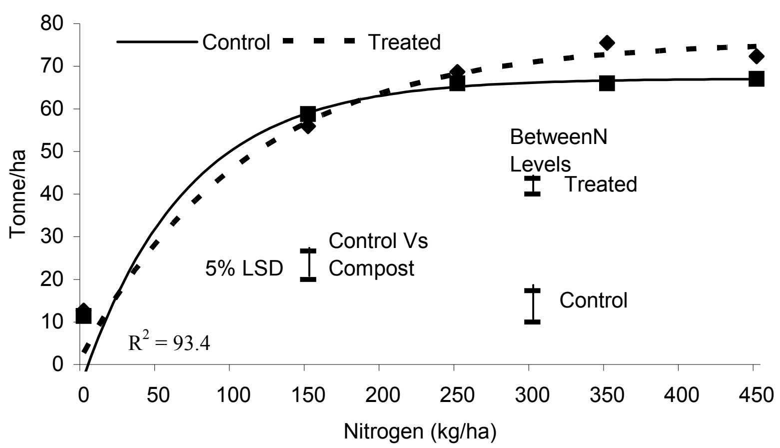


Figure 1.8. Weight of lettuce harvested on day 41.

Nutrient content of whole lettuce

Whole plant concentrations of Nitrogen, Phosphorus and Potassium showed a quadratic response to applied nitrogen (P < 0.001). There was no difference between treatments (Table 1.42).

Table 1.42. Whole lettuce plant nutrient content

Treatment	Nitrogen application kg/ha				
	0	150	250	350	450
Nitrogen	1.45	2.57	3.22	3.57	3.87
Phosphorus	0.47	0.58	0.64	0.68	0.69
Potassium	4.39	5.61	5.87	5.92	5.58

Analysis of wrapper leaf at harvest

Compost increased Potassium and Calcium but lowered Manganese and Zinc concentration of youngest mature wrapper leaf taken at harvest (Table 1.43).

Table 1.43. Analysis of lettuce wrapper leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range**
% db				
Phosphorus	0.53	0.53	ns	0.55–0.65
Potassium	4.9	5.2	0.27	5.5–6.0
Sodium	0.84	0.84	ns	< 0.5–1.0
Calcium	0.86	0.97	0.07	1.4–2.0
Magnesium	0.25	0.26	ns	0.3–0.7
Sulphur	0.24	0.24	ns	0.3–0.32
mg/kg				
Boron	27.0	26.3	ns	25–55
Copper	5.75	5.40	ns	10–18
Iron	842	921	ns	50–500
Manganese	58.2	37.0	13.8	50–300
Molybdenum				0.08–0.17
Zinc	55.8	39.5	7.5	30–100

* lsd - Least significant difference P = 0.05.
** Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.

Soil analysis at planting

Nitrogen

Within the main plot stratum total soil nitrogen increased with increased rate of compost (P < 0.001; Table 1.44).

Table 1.44. Total nitrogen content of soil at planting (% db)

Treatment	Nitrogen application kg/ha				
	0	150	250	350	450
Control	0.028	0.031	0.029	0.030	0.035
Compost 30 m^3	0.052	0.050	0.050	0.048	0.049
Compost 60 m^3	0.063	0.067	0.067	0.065	0.065
lsd 5%	*Control vs Composts*		*0.009*		
	Compost 30 m^3 v 60 m^3		*0.008*		
	Controls between Nitrogen		*0.01*		
	Compost 30 m^3 and 60 m^3 between N		*0.007*		

Nitrogen present as Nitrate

The level of soil Nitrogen present as Nitrate at the time of planting was high for all plots but plots treated with different compost types showed a different quadratic response to applied nitrogen (P = 0.008). Plots treated with Compost A recorded higher levels of Nitrogen present as Nitrate (Table 1.45).

The higher level of nitrate nitrogen present in soils treated with compost A would have contributed to the positive growth response recorded for plots treated with compost. Compost B, which performed poorly in the previous carrot crop, did not increase plant available nitrogen.

Nitrate present as Ammonium

Nitrogen present as Ammonium averaged 2.55 mg/kg and showed no difference between treatments.

Table 1.45. Soil Nitrogen present as Nitrate at planting (mg/kg)

Treatment	Nitrogen application kg/ha				
	16	150	250	350	450
Control	5.25	8.25	8.75	11.50	12.50
Compost A	3.38	13.25	10.75	14.00	13.50
Compost B	5.12	8.13	8.13	10.75	11.38
lsd 5%	*Control vs Composts*		*3.33*		
	Compost A v B		*2.72*		
	Controls between Nitrogen		*3.72*		
	Compost between Nitrogen		*2.63*		

Nitrogen content of soil at harvest

Total Nitrogen Content of Soil at harvest was marginally lower than that recorded at planting and within the main plot stratum increased with compost rate (Table 1.46).

Table 1.46. Soil Nitrogen % db

Control	0.025a*
30 m^3	0.047b
60 m^3	0.058c

* Values followed by a different subscript are different (P > 0.05).

Nitrogen as nitrate

Soil levels of Nitrogen present as Nitrate were lower than those recorded at planting and differences between composts and application rate were no longer significant (Table 1.47).

Table 1.46. Soil Nitrogen as Nitrate (mg/kg db)

Treatment	mg/kg
Control	3.70
Compost A	3.70
Compost B	4.63*

* Values are not different (P > 0.05).

Nitrogen present as Ammonium

Levels of soil Nitrogen present as ammonium remained low (Table 1.48).

Table 1.48. Soil Nitrogen as Ammonium (mg/kg db)

Treatment	mg/kg
Control	2.25*
30 m^3	2.60
60 m^3	2.98

* Values are not different (P > 0.05).

Growing conditions

Crop management and irrigation scheduling met recommendations, Figure 1.9.

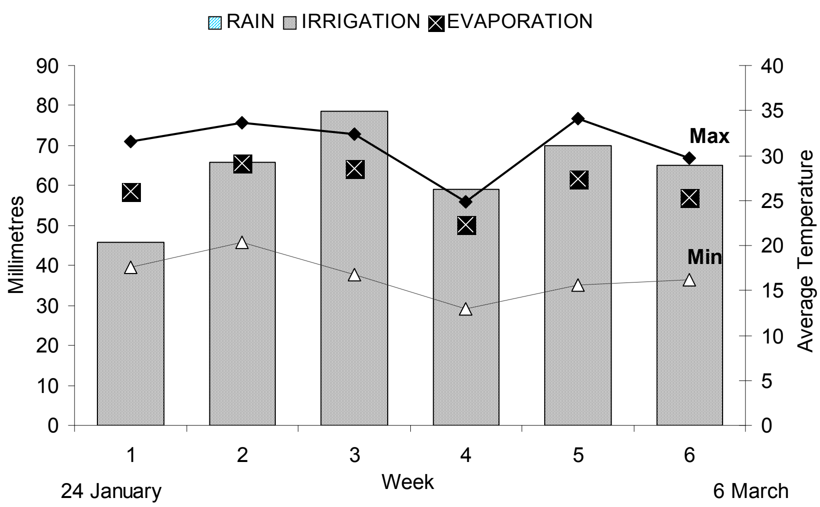


Figure 1.9. Weather conditions lettuce crop 3.

Nutrient leaching

All treatments measured leached a similar amount of water with 36% (151 mm) of the rain (0 mm) and irrigation (418 mm) being collected in the drainage lysimeters. Evaporation was 405 mm and the apparent crop water use (rain + irrigation – drainage) was 267 mm or 66 per cent of evaporation.

Nutrients collected in the lysimeters is recorded in Table 1.49.

Table 1.49. Nutrients collected in drainage lysimeters during crop growth

Compost	Rate m^3/ha	Applied Nitrogen kg/ha	Total Nitrogen kg/ha	N as NH_4 kg/ha	N as NO_3 kg/ha	Organic N kg/ha	Potassium leached kg/ha
Control	0	0	23.3	0.9a	19.5	2.9	
Control	0	250	54.2	2.8b	43.8	7.7	26.9a
A	30	250	65.3	1.2a	52.4	11.7	38.7a
B	30	250	53.5	1.5a	42.8	9.3	40.2a
A	60	250	92.8	2.5a	78.8	11.6	131.5b
B	60	250	38.5	0.5a	29.4	8.7	91.5b
A	60	450	101.2	0.3a	92.9	8.1	
B	60	450	97.4	0.4a	82.7	14.3	

* Values followed by a common subscript are not different ($P > 0.05$). Values are the mean of 3 replications.

Nitrogen

While there was a trend for compost A to leach more Nitrogen than compost B this was not significantly different.

Potassium

The equivalent of 6 per cent of the Potassium applied to control plots was collected in the lysimeters. Leaching increased when 60 m^3 of compost was applied. All plots received 450 kg/ha of Potassium fertiliser and 30 m^3 of compost added an additional 70 kg/ha.

Phosphorus

No Soluble Reactive Phosphorus was detected (< 0.01 mg/L) in leach samples. While more than half the samples recorded levels of Total Phosphorus of 0.1 mg/L or greater it was only possible to estimate that less than 200 mg/ha of Phosphorus was leached during the 6 week growing period.

Discussion

Chemical analysis indicated that Compost A (A4 Appendix 1.1) should impact better on plant growth than Compost B (2B Appendix 1.1). While Compost A did increase levels of soil nitrate at planting (Table 1.44) at 20 days only the linear response of crop growth to applied nitrogen between control and compost treated plots combined, approached significance (Table 1.39). At final harvest this comparison became significant (Table 1.40) with compost treated plots producing about 10 per cent more at higher levels of nitrogen application.

Compost A but not Compost B gave a higher processed head weight as a percentage of total plant weight (Table 1.41).

The nitrogen, phosphorus and potassium content of whole plant showed a linear increase to applied nitrogen but did not differ between treatments. The 450 kg of potassium applied across all treatments prevented the crop from responding to the additional potassium supplied by the compost by increasing plant concentration.

Soil nitrogen continued to increase with compost application (Tables 1.44 and 46). The elevated levels and treatment differences for soil nitrate recorded at planting (Table 1.45) had disappeared at harvest (Table 1.47).

Compost did not increase the leaching of nitrogen but potassium leaching increased when 60 m^3 of compost was applied (Table 1.49).

Carrot - Crop 4

The following compost treatments were applied and incorporated into the soil together with an application of 200 kg per hectare of phosphorus and trace minerals one week prior to seeding carrots, variety Stefano, on 28 March 2002.

Treatment	Compost rates m^3/ha	Nitrogen rate kg N/ha	
Control	Nil	N1	Nil
A1/B1	30	N2	160
A2/B2	60	N3	240
		N4	320
		N5	400

Nitrogen treatments were applied as potassium nitrate and sulphate of ammonia in weekly percentages proportional to growth by watering can together with a total of 300 kg/ha of potassium, 20 kg of magnesium and 1.5 kg of Boron. The carrots grew well and were harvested at 138 days on 13 August. Intermediate harvest yields were recorded on 11 June (75 days) and 18 July (112 days).

Compost quality

Compost A had a high C/N ratio (24) contained all its plant available Nitrogen as Ammonium (27 mg/L) and contained little freely available carbon (NDI = 0.68).

Compost B was the compost used as A for the previous lettuce crop and had matured further loosing plant available nitrogen present as Nitrate (89 to 4.2 mg/L), increasing nitrogen percentage to 1.7% and reducing the C/N ratio to 18 (Appendix 1.1 Compost 5A and 4B).

Compost	Carbon Nitrogen Ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 5A	24	0.68	74	1.2	27	< 0.1
Compost 4B	18	0.45	91	1.7	4.2	< 0.1

First harvest 75 days

Plant density averaged 70 plants per m^2 and there was no difference between treatments.

Total plant weight

Within the main plot stratum total plant weight of Compost B and Control was greater than Compost A (P = 0.004; Table 1.50) but the average of Compost A and B at 60 m^3 produced less growth (P = 0.007; Table 1.51).

Table 1.50. Total plant weight at 75 days (t/ha)

Treatment	t/ha
Control	25.1a*
Compost A	24.1b
Compost B	26.0a

* Values followed by a common subscript are not different (P > 0.05).

Table 1.51. Total plant weight at 75 days (t/ha)

Treatment	t/ha
Control	25.1a*
30 m^3	25.9a
60 m^3	24.1b

* Values followed by a common subscript are not different (P > 0.05).

The differences in total plant weight were the result of differences in both Top and Root growth (P < 0.01; Tables 1.52, 1.53 and 1.54).

Table 1.52. Weight of carrot top at 75 days (t/ha)

Treatment	t/ha
Control	16.6a*
Compost A	15.6b
Compost B	16.8a

* Values followed by a common subscript are not different (P > 0.05).

Table 1.53. Weight of carrot top at 75 days (t/ha)

Treatment	t/ha
Control	16.6a*
30 m^3	16.9a
60 m^3	15.5b

* Values followed by a common subscript are not different (P > 0.05).

Table 1.54. Weight of carrot root at 75 days (t/ha)

Treatment	t/ha
Control	8.5a
Compost A	8.4a
Compost B	9.2b

* Values followed by a common subscript are not different (P > 0.05).

Harvest - 112 days

Within the main plot stratum Compost A produced less Total Plant Weight than Compost B treated plots (P = 0.013; Table 1.55). While the linear response of Total Plant Weight to applied nitrogen for the average of Compost treated plots was lower than for Control plots (P = 0.004; Table 1.56) this appeared to be the result of poor growth of Compost A treated plots relative to B (Table 1.57).

Table 1.55. Total plant weight at 112 days (t/ha)

Treatment	t/ha
Control	65.3ab*
Compost A	63.7b
Compost B	67.0a

* Values followed by a common subscript are not different (P > 0.05).

Table 1.56. Total plant weight at 112 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	112	168	224	280
Control	14.8	65.0	74.9	83.4	88.2
Compost	24.1	64.6	73.6	81.4	83.0
lsd 5%	*Control vs Composts*		*6.6*		
	Controls between Nitrogen		*8.6*		
	Compost between Nitrogen		*4.3*		

Table 1.57. Total plant weight at 112 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	112	168	224	280
Control	14.8	65.0	74.9	83.4	88.2
Compost A	23.5	63.2	71.5	79.2	81.1
Compost B	24.65	66.0	75.8	83.5	84.9

Carrot top

Within main plots Compost B applied at 60 m^3/ha produced more Carrot Top than any other treatment and when applied at 30 m^3 produced more than compost A applied at 30 m^3 (P = 0.013; Table 1.58).

Table 1.58. Weight of carrot top at 112 days (t/ha)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	14.0ab*		
Compost A		13.4a	13.8ab
Compost B		14.1b	15.4c

* Values followed by a common subscript are not different (P > 0.05).

The difference within main plots was generated by non significant increased top growth recorded by Compost B at the lower rates of applied nitrogen (Table 1.59).

Table 1.59. Total weight of carrot top at 112 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	112	168	224	280
Control	1.91	10.7	15.6	19.4	22.4
Compost A	3.1	10.9	15.0	18.5	21.1
Compost B	3.5	12.0	16.0	20.3	21.2

Carrot root

Within main plots Compost B produced a greater weight of harvested carrot root than Compost A but similar to the Control ($P < 0.05$; Table 1.60). Compost treated plots produced more carrots when no nitrogen was applied ($P < 0.05$).

Table 1.60. Weight of carrot roots at 112 days (t/ha)

Treatment	Nitrogen application kg/ha					
	0	112	168	224	280	Average
Control	12.9a*	54.3	59.4	64.0	65.8	51.3ab
Compost A	20.2b	52.4	52.4	56.6	60.4	50.1b
Compost B	21.3b	53.8	59.5	63.4	63.0	52.2a

* Within column values followed by a common subscript are not different ($P > 0.05$).

Final harvest - 138 days

Total plant weight

There were no main plot differences for the total plant weight of carrot produced. There was an interaction between applied nitrogen and compost treatment ($P = 0.025$) and the linear response of total plant weight to applied nitrogen was different for control and compost treated plots ($P = 0.001$; Table 1.61).

Table 1.61. Weight of total plant at 138 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	160	240	320	400
Control	20.7	87.1	99.2	109.8	111.5
Compost	33.8	92.2	98.5	108.3	105.0

lsd 5%	*Control vs Composts*	*9.1*
	Controls between Nitrogen	*10.9*
	Compost between Nitrogen	*5.5*

Carrot top

Within main plots compost produced more carrot top ($P = 0.035$). This was the result of greater top growth at low rates of nitrogen application and the control and treated plots showed a different linear response to applied Nitrogen (Table 1.62; $P = 0.04$).

Table 1.62. Weight of carrot top at 138 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	**160**	**240**	**320**	**400**
Control	1.52	9.77	14.01	18.26	20.62
Compost	2.80	11.52	15.05	18.61	19.94
lsd 5%	*Control vs Composts*		*1.45*		
	Controls between Nitrogen		*1.85*		
	Compost between Nitrogen		*0.92*		

Carrot root

There were no main plot differences for the weight of carrot root produced. There was an interaction between applied nitrogen and compost treatment (P = 0.023). Compost treated plots produced more carrot root at low rates of applied nitrogen and the linear response of weight of carrot root to applied nitrogen was different for control and compost treated plots (P = 0.001; Table 1.63).

Table 1.63. Weight of carrot root at 138 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	**160**	**240**	**320**	**400**
Control	19.6	77.4	85.2	91.5	90.9
Compost	31.0	80.7	83.4	89.7	85.1
lsd 5%	*Control vs Composts*		*8.2*		
	Controls between Nitrogen		*9.8*		
	Compost between Nitrogen		*4.9*		

Grade A,B carrots

The linear response of Control and Treated plots for Grade A,B Carrots to applied nitrogen was different (P = 0.056), i.e. there was a trend for compost treated plots to produce more Grade A,B carrots because of a lower level of rejection (P = 0.001). This result was influenced by a higher percentage of carrots produced in Control plots receiving no applied nitrogen being under size (Tables 1.64; 65).

Table 1.64. Marketable yield of Grade A,B carrots (t/ha)

Treatment	Nitrogen application kg/ha				
	0	**160**	**240**	**320**	**400**
Control	4.1	64.3	70.3	71.3	70.2
Compost	15.4	67.6	71.2	73.4	69.0
lsd 5%	*Control vs Composts*		*9.6*		
	Controls between Nitrogen		*11.5*		
	Compost between Nitrogen		*5.8*		

Table 1.65. Per cent of reject carrots (by weight)

Treatment	Nitrogen application kg/ha				
	0	160	240	320	400
Control	85.2	17.0	17.8	21.9	22.8
Compost	52.8	16.5	14.9	18.1	18.7
lsd 5%	*Control vs Composts*		*12.7*		
	Controls between Nitrogen		*15.1*		
	Compost between Nitrogen		*7.5*		

Nitrogen, Phosphorus and Potassium content of carrot top

Nitrogen

Within main plots the nitrogen content of carrot tops plots treated with 30 m^3 of Compost A were fractionally higher than plants coming from Control and plots treated with 30 m^3 of Compost B ($P = 0.034$; Table 1.66). There was a linear response to applied nitrogen ($P < 0.001$; Table 1.67).

Table 1.66. Nitrogen content of carrot top at harvest (% db)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	2.01a*		
Compost A		2.10b	2.06ab
Compost B		2.00a	2.06ab

* Values followed by a common subscript are not different ($P > 0.05$).

Table 1.67. Nitrogen content of carrot top at harvest (% db)

Treatment	Nitrogen application kg/ha				
	0	160	240	320	400
Control	1.755	1.912	1.897	2.137	2.332
Compost A	1.877	1.979	2.030	2.137	2.330
Compost B	1.804	1.950	2.002	2.125	2.280

Phosphorus

Phosphorus content of carrot top at harvest declined with increasing application of Nitrogen and was similar for all treatments (Table 1.68).

Table 1.68. Phosphorus content of carrot top at harvest (% db)

Treatment	Nitrogen application kg/ha				
	0	160	240	320	400
Control	0.588	0.292	0.245	0.230	0.252
Compost	0.601	0.274	0.226	0.223	0.234

Potassium

Within the main plot stratum the Potassium content of carrot top at harvest was increased by the application of 60 m^3 of compost (P = 0.016) and showed a quadratic response to applied nitrogen (P < 0.001; Table 1.69).

Table 1.69. Potassium content of carrot top at harvest (% db)

Treatment	Nitrogen application kg/ha					
	0	150	250	350	450	Average
Control	3.487	4.210	4.397	3.890	3.457	3.89a*
Compost 30 m^3	4.034	4.724	4.637	4.205	3.722	4.26ab
Compost 60 m^3	4.171	5.062	4.766	4.606	4.415	4.60b

* Values followed by a common subscript are not different (P > 0.05).

Nitrogen, Phosphorus and Potassium content of carrot root

Nitrogen

Nitrogen concentration of carrot root at harvest increased with applied Nitrogen but was similar for control and compost treated plots (Table 1.70).

Table 1.71. Nitrogen content of carrot root at harvest (% db)

Treatment	Nitrogen application kg/ha				
	0	160	240	320	400
Control	0.527	1.000	1.322	1.487	1.910
Compost	0.576	0.937	1.282	1.576	1.821

Phosphorus

Within the main plot stratum Phosphorus content of carrot root at harvest was not different. The linear response of Phosphorus content to applied nitrogen for Control and Compost treated plots was different (P = 0.05; Table 1.71).

Table 1.71. Phosphorus content of carrot root at harvest (% db)

Treatment	Nitrogen application kg/ha				
	0	160	240	320	400
Control	0.318	0.348	0.350	0.350	0.408
Compost	0.328	0.336	0.341	0.355	0.368
lsd 5% Control vs Compost			*0.027*		
lsd 5% Control between N levels			*0.033*		
lsd 5% Compost between N levels			*0.017*		

Potassium

Within main plots carrot roots from control plots measured 2.34% db Potassium and carrots from Compost treated plots 2.59% (P < 0.001). Control and treated plots responded differently to applied Nitrogen with treated plots giving higher Potassium content at all levels of applied Nitrogen (P = 0.011; Table 1.72).

Table 1.72. Potassium content of carrot root at harvest (% db)

Treatment	Nitrogen application kg/ha				
	0	160	240	320	400
Control	2.675	2.622	2.392	1.975	2.045
Compost	2.721	2.837	2.601	2.437	2.354
lsd 5%	*Control vs Compost*		*0.19*		
lsd 5%	*Control between N levels*		*0.24*		
lsd 5%	*Compost between N levels*		*0.12*		

Analysis of carrot youngest fully mature leaf at harvest

The analysis of YFML at harvest showed Compost treated plots to have lower levels of most minerals. Despite the continued application of Trace Elements Copper, Manganese and Zinc levels continued to be low (Table 1.73).

Table 1.73. Analysis of carrot youngest fully mature leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range*
% db				
Phosphorous	0.30	0.29	0.01	0.3–0.4
Potassium	> 4.00	> 4.00	NA	1.3–1.5
Sodium	1.10	0.89	ns	0.7–4.5
Calcium	1.90	1.80	ns	1.8–2
Magnesium	0.24	0.255	0.01	0.35–0.40
Sulphur	0.32	0.32	ns	0.3–0.6
mg/kg				
Boron	38.6	39.2	ns	29–35
Copper	3.60	3.13	0.37	5–7
Iron	425	356	38	120–350
Manganese	56	27	5	190–350
Zinc	27	19	1.6	20–50

* Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.

Soil analysis at planting 0-15 cm

Samples were taken from plots receiving 0, 240 and 400 kg of applied Nitrogen only.

Within the main plot stratum Soil Total Nitrogen increased with rate of Compost:Control 0.026; 30 m^3 0.474 and 60 m^3 0.622% db ($P = < 0.001$).

Nitrogen present as nitrate

Soil nitrate levels at planting were high and reflected the turning of residue from the previous lettuce crop into the soil. Compost treated plots which had not received applied nitrogen were higher than control plots for the corresponding treatment ($P = 0.09$; Table 1.74).

Table 1.74. Soil Nitrogen as Nitrate at planting (mg/kg db)

Treatment	Nitrogen application kg/ha		
	0	240	400
Control	4.00	12.00	15.50
Compost	10.69	14.50	15.25

Nitrogen present as Ammonium

Soil content of Nitrogen present as ammonium was higher in control plots (P < 0.001). Control and Treated plots were different for different rates of applied nitrogen (P = 0.001; Table 1.75).

Table 1.75. Soil Nitrogen as Ammonium at planting (mg/kg db)

Treatment	Nitrogen application kg/ha		
	0	240	400
Control	4.25	2.00	7.00
Compost	2.50	1.81	1.56
lsd 5% Control vs Compost		*1.81*	
lsd 5% Control between N levels		*2.40*	
lsd 5% Compost between N levels		*1.18*	

Soil analysis at harvest 0-15 cm

Soil Total Nitrogen at harvest was similar to that recorded at seeding.

Soil Nitrogen present as Nitrate at harvest

Nitrate nitrogen levels had fallen dramatically and differences were unlikely to impact significantly on plant growth (Table 1.76).

Table 1.76. Soil Nitrogen present as Nitrate at harvest (mg/kg)

Treatment	Nitrogen application kg/ha		
	0	240	400
Control	1.50	1.25	1.00
Compost	1.75	1.94	2.50
lsd 5% Control vs Compost		*0.62*	
lsd 5% Control between N levels		*0.83*	
lsd 5% Compost between N levels		*0.41*	

Soil Nitrogen present as Ammonium at harvest

The differences in Soil Nitrogen present as Ammonium seen at planting had diminished but within the main plot stratum it increased with rate of applied compost (P < 0.001; Table 1.77).

Table 1.77. Soil Nitrogen as Ammonium at harvest (mg/kg db)

Control	1.42a*
30 m^3	2.08b
60 m^3	2.92c

* Values followed by a different subscript are different (P < 0.05).

Phosphorus

All sub plots which had received the fourth highest rate of nitrogen application were analysed for Bicarbonate phosphorus (Table 1.78).

Table 1.78. Soil Phosphorus (bicarbonate extracted) at harvest (mg/kg db)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	63.3a*		
Compost A		95.2b	116.5d
Compost B		106.2c	112.cd

* Values followed by a common subscript are not different (P > 0.05).

Compost application had increased plant available Phosphorus and differences between Compost type and rate were recorded.

Growing conditions

Growing conditions were typical for Autumn-Winter. Irrigation and crop management met recommendations (Figure 1.10).

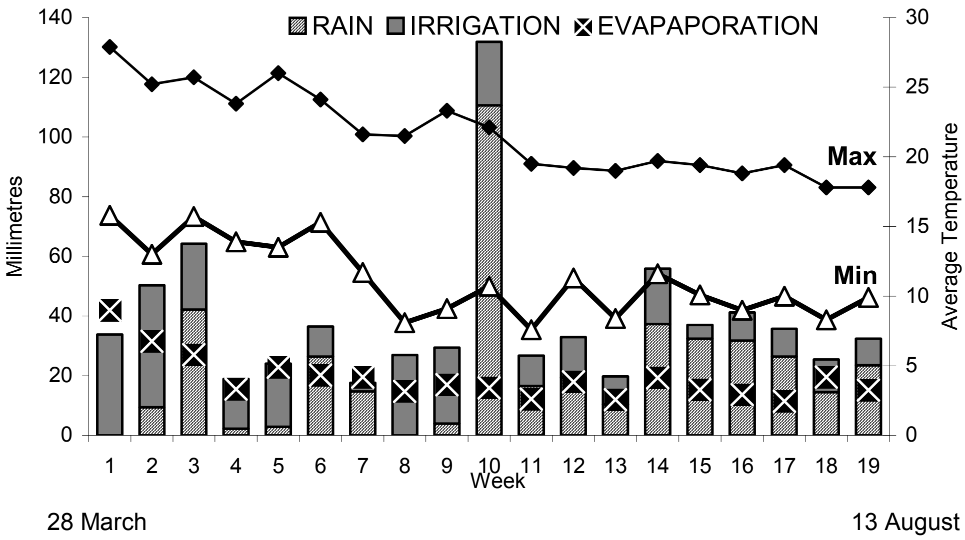


Figure 1.10. Weather conditions carrot crop 4.

Nutrient leaching

All treatments measured leached a similar amount of water with 61% (452 mm) of the rain (425 mm) and irrigation (316 mm) being collected in the drainage lysimeters. Evaporation was 364 mm and the apparent crop water use (rain + irrigation – drainage) was 289 mm or 79.4 per cent of evaporation.

The quantity of Nitrogen and Potassium collected in drainage lysimeters under selected treatments is given in Table 1.79.

Nitrogen

Separate analysis of plots treated with 240 kg of nitrogen fertiliser showed a trend for plots spread with 30 m^3 of compost to leach less total Nitrogen ($P = 0.08$) and nitrogen as nitrate ($P = 0.065$) than Control and plots spread with 60 m^3.

Plots spread with 60 m^3 of Compost B and treated with 400 kg of fertiliser nitrogen leached more organic nitrogen.

Table 1.79. Nutrients collected in drainage lysimeters during crop growth

Compost	Rate m^3/ha	Applied Nitrogen kg/ha	Total Nitrogen kg/ha	N as NH_4 kg/ha	N as NO_3 kg/ha	Organic N kg/ha	Potassium leached kg/ha
Control	0	0	56.5a	2.25ab	48.3a	5.9a	
Control	0	240	123.3a	5.16b	96.4ab	21.7a	84
A	30	240	70.1a	1.07a	52.6ab	16.4a	109
B	30	240	101.1a	2.07ab	87.5ab	11.5a	122
A	60	240	122.8a	4.25b	103.3ab	15.3a	198
B	60	240	131.9b	2.12ab	111.3ab	18.5a	184
A	60	400	192.8bc	0.36a	178.9c	13.5a	
B	60	400	242.8c	0.53a	192.5c	49.8b	

* Values followed by a common subscript are not different ($P > 0.05$). Values are the mean of 3 replications.

Phosphorus and Potassium

Plots received 200 kg/ha of Phosphorus before seeding and 300 kg/ha of Potassium was applied during the growing period.

No Soluble Reactive Phosphorus (< 0.01 mg/L) was detected in leach samples and only slightly more than half the samples showed detectable levels (0.1 or > mg/L) of total phosphorus. Less than 500 mg /ha of Phosphorus was leached during the 20 week cropping period.

The equivalent of 30 per cent of the Potassium applied was collected in the lysimeters. Variation between replicates meant no difference between treatments was found.

Discussion

On analysis Compost B was expected to perform better than A. Compost A had a high C/N ratio, contained a small amount of plant available nitrogen as ammonium and had a NDI of 0.68 which indicated it had a low level of available carbon. Compost B had performed well in the previous lettuce crop and matured further in storage (Compost 5A and 4B Appendix 1.1).

Whole plant, Top and Root growth at 75 days confirmed this assessment with Compost B giving higher Total Plant and Top weight than Compost A and more root than Control and Compost A treated plots (Tables 1.50-1.54).

At 112 days Compost A gave less Total Plant Growth than Compost B and the Controls (Table 1.55). While the linear response of Total Plant Weight to applied nitrogen was lower for compost treated plots this was arguable the result of the poor growth recorded by Compost A (Table 1.57). Differences were the result of reduced Top growth rather than root (Tables 1.58 and 1.59).

When no nitrogen was applied compost treated plots produced more carrots than control plots indicating that the nitrogen status of the compost treated plots had increased.

At the final harvest the linear trend of Total Plant Weight to applied nitrogen was higher for Control plots but Compost treated plots produced more Total Plant at low rates of nitrogen application (Table 1.61). Differences between Compost type had largely disappeared but the trend for Compost to increase Top and Root growth at low rates of nitrogen application continued (Tables 1.62 and 1.63).

Carrots from Compost treated plots gave a better grading percentage and the trend was for Compost to produce more grade A,B carrots (Tables 1.64 and 1.65).

Differences in plant nutrient content was small but there was an indication that the nitrogen content of carrot Top was higher for Compost treated plots at low levels of nitrogen application (Table 1.67).

The additional Potassium supplied by the Compost continued to increase the Potassium content of carrot Top and Roots (Tables 1.68, 1.69 and 1.72).

Leaf analysis at harvest showed compost reduced the leaf concentration of most minerals notably Manganese and Zinc. Copper levels continued to be low in all treatments (Table 1.73).

Soil analysis confirmed Compost was increasing Soil Nitrogen but with the exception of Control plots receiving no applied nitrogen Soil Nitrogen present at planting as Nitrate was high for all treatments. Nitrogen present as Ammonium was higher in Control plots (Tables 1.74 and 1.75).

The levels of Soil Nitrogen present as Nitrate had dropped dramatically at harvest (Table 1.76) and luxury levels of plant available Phosphorus were recorded in Compost treated plots.

There was a tendency for Compost to reduce the amount of nitrogen leaching into lysimeters installed under plots receiving 240 kg of applied nitrogen.

Results confirmed that carrots were sensitive to compost quality and product which does not meet the minimum standards suggested in Appendix 1.1 will potentially reduce carrot yield. The nitrogen being applied with the continued use of compost was accumulating in the soil and contributing a low level of plant available nitrogen for crop growth. The trend for compost to increase carrot quality was similar to that recorded in the first carrot crop on this site.

Lettuce - Crop 5

Iceberg lettuce seedlings, variety *magnum*, were transplanted on 26 September 2002 and the following fertiliser treatments applied weekly by watering can for 7 weeks. The lettuce was harvested 54 days later on 19 November 2002. Intermediate growth was recorded on 24 October (28 days).

Treatment	Compost rates m^3/ha	Nitrogen rate kg N/ha	
Control	Nil	N1	Nil
A1/B1	30	N2	150
A2/B2	60	N3	250
		N4	350
		N5	450

Phosphorus was applied at a rate of 960 kg per hectare of single superphosphate (SSP) together with a complete trace element mix as a single application across the site prior to planting. In order to balance the plots for the phosphorus being applied in the compost additional SSP was applied to control plots at a rate equivalent to 1,140 kg/ha. All treatments received 450 kg of Potassium and 25 kg of Magnesium per hectare. The Nitrogen treatments, together with Potassium and Magnesium were applied by watering can as weekly applications apportioned; week 1, 3.0; week 2, 7.0; week 3, 12.5; week 4, 27.5; week 5, 27.5; week 6, 12.5 and week 7 10 per cent of the total.

Compost quality

Compost A met our criteria for C/N ratio, toxicity and NDI but it contained 150 mg/L of nitrogen as ammonium and no nitrate. This indicated it had not entered the maturation phase and was not composted sufficiently. Compost B had a high C/N ratio of 25 contained its plant available nitrogen in the ammonium form and the NDI of 0.37 showed it still contained readily available carbon (Appendix 1.1 Compost 7 & 6B).

Compost	Carbon Nitrogen Ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	NH_4 + NO_3	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 7A	20	0.51	79	1.4	140	< 0.10
Compost 6B	25	0.37	100	1.2	78	< 0.10

Harvest - 28 days

Total weight of plant harvested at 28 days showed a quadratic response ($P < 0.001$) to applied nitrogen but no difference between treatments (Table 1.80).

Table 1.80. Total lettuce plant weight (t/ha) at day 28

Treatment	Applied nitrogen kg/ha				
	16	50	75	95	117
Control	2.2	6.5	8.1	8.7	10.1
Compost	2.9	8.9	8.1	8.9	9.7

Final harvest - 54 days

Plants were harvested a few days beyond optimum. There was a quadratic response to applied nitrogen but no difference between treatments for Total and Processed Head weight (Table 1.81).

Table 1.81. Final lettuce harvest of head and total plant weight (t/ha)

Treatment	*Lettuce*	*Applied Nitrogen kg/ha*				
		16	*150*	*250*	*350*	*450*
Control	*Total plant*	*9.07*	*59.7*	*77.0*	*80.2*	*83.6*
	Head	*0.0*	*44.1*	*58.2*	*61.6*	*62.2*
Compost	*Total plant*	*12.0*	*57.3*	*74.7*	*78.8*	*80.1*
	Head	*0.0*	*42.6*	*57.0*	*60.3*	*61.4*

Percentage head

On average Compost A increased the percentage of processed head (Table 1.82).

Table 1.82. Lettuce processed head (%)

Treatment	Lettuce
Control	60.2a*
Compost A	61.1b
Compost B	60.5a

* Values followed by a common subscript are not different (P > 0.05).

Nutrient content of Whole Plant

Nitrogen

Compost increased Nitrogen content of plants growing in plots receiving no applied nitrogen P = 0.07) and caused the linear response of Nitrogen content of Whole Plant to applied Nitrogen for Control and Compost treated plots to be different (P = 0.012; Table 83). The response was for Compost to give lower concentrations of nitrogen at high rates of applied Nitrogen.

Table 1.83. Nitrogen content of whole plant (% db)

Treatment	*Nitrogen application kg/ha*				
	16	*150*	*250*	*350*	*450*
Control	*1.80*	*2.70*	*3.69*	*4.14*	*4.28*
Compost	*2.10*	*2.66*	*3.72*	*4.03*	*4.17*

lsd	5% Control vs Compost	0.23
	5% Control between N levels	0.28
	5% Compost between N levels	0.14

Phosphorus

Phosphorus content of whole plant at harvest was above the recognised normal range of 0.55 to 0.65 per cent. Differences between control and compost treated plots (Table 1.84) were consistent with the level of soil phosphorus measured at the previous harvest of carrots and the additional phosphorus applied to control plots (Table 1.78).

Table 1.84. Phosphorus content of Whole Plant at Harvest (% db)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	0.719a*		
Compost A		0.663b	0.684ab
Compost B		0.690ab	0.671ab

* Values followed by a common subscript are not different ($P > 0.05$).

Potassium

Potassium content of whole plant was higher from plots receiving 30 m^3 of compost (Table 1.85).

Table 1.85. Potassium Content of Whole Plant at Harvest (% db)

Treatment	Lettuce
Control	5.98a*
Compost 30 m^3	6.16b
Compost 60 m^3	5.94a

* Values followed by a common subscript are not different ($P > 0.05$).

Analysis of youngest mature wrapper leaf at harvest

The use of compost increased the Calcium, Magnesium and Sulphur content of lettuce youngest mature wrapper leaf at harvest but reduced Manganese and Zinc concentrations (Table 1.86).

Table 1.86. Analysis of lettuce wrapper leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range**
% db				
Nitrogen	3.46	3.53	ns	
Phosphorous	0.71	0.66	ns	0.55–0.65
Potassium	7.59	7.92	ns	5.5–6.0
Sodium	0.98	0.96	ns	< 0.5–1.0
Calcium	1.32	1.52	0.19	1.4–2.0
Magnesium	0.39	0..42	0.027	0.3–0.7
Sulphur	0.30	0.33	0.026	0.3–0.32
mg/kg				
Boron	38.5	37.9	ns	25–55
Copper	6.5	6.4	ns	10–18
Iron	964	1086	ns	50–500
Manganese	101	42	13.8	50–300
Molybdenum				0.08–0.17
Zinc	90	44	6.9	30–100

* lsd - Least significant difference P = 0.05.
** Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.

Soil analysis at planting

Organic Carbon increased with rate of compost application (P < 0.001) and the linear response of soil carbon to applied Nitrogen was different for each rate of Compost applied (P = 0.062; Table 1.87). Control plots increased with the rate of applied nitrogen, Compost at 30 m^3 declined with increased rate of Nitrogen application and 60 m^3 recorded similar levels of soil carbon for all Nitrogen application rates.

Table 1.87. Soil organic carbon content (% db) at planting

Treatment	*Nitrogen application kg/ha*				
	0	*150*	*250*	*350*	*450*
Control	*0.475*	*0.545*	*0.518*	*0.528*	*0.598*
Compost 30 m^3	*0.901*	*0.856*	*0.766*	*0.760*	*0.770*
Compost 60 m^3	*0.935*	*1.01*	*0.959*	*0.979*	*0.930*

lsd 5%	Control vs Composts	0.141
	Compost 30 m^3 v 60 m^3	0.115
	Controls between Nitrogen	0.157
	Compost 30 m^3 and 60 m^3 between N	0.111

Nitrogen

Soil Nitrogen increased with the application of compost (P < 0.001; Table 1.88).

Table 1.88. Soil nitrogen (% db) at planting

Treatment	Lettuce
Control	0.025a*
Compost 30 m^3	0.046b
Compost 60 m^3	0.063c

* Values followed by a common subscript are not different (P > 0.05).

Nitrogen as Nitrate

Soil Nitrogen as nitrate was lower than the previous carrot crop and on average was higher for Compost A (P = 0.013) and higher when applied at 30 m^3 (P < 0.05; Table 1.89).

Table 1.89. Soil Nitrate nitrogen (mg/kg db) at planting associated with compost type and rate

Treatment	Lettuce
Control	2.95a*
Compost A	4.88b
Compost B	4.25c
Compost 30 m^3	4.80c
Compost 60 m^3	4.33b

* Values followed by a common subscript are not different (P > 0.05).

Nitrogen as Ammonium

Compost treated plots gave lower levels of Nitrogen as Ammonium (P < 0.01) and the linear response of Nitrogen as Ammonium to applied Nitrogen was different for rates of compost applied (P = 0.03; Table 1.90).

Table 1.90. Nitrogen as ammonium content of soil at planting (% db)

Treatment	*Nitrogen application kg/ha*				
	16	***150***	***250***	***350***	***450***
Control	*2.25*	*3.75*	*3.75*	*4.25*	*4.00*
Compost 30 m^3	*2.38*	*2.38*	*2.00*	*2.38*	*3.50*
Compost 60 m^3	*2.75*	*2.88*	*2.62*	*2.12*	*2.38*

lsd 5%	Control vs Composts	1.314
	Compost 30 m^3 v 60 m^3	1.073
	Controls between Nitrogen	1.421
	Compost 30 m^3 and 60 m^3 between N	1.005

Soil analysis at harvest

Organic Carbon

Organic Carbon content of soil at harvest had changed little during the period of the crop and was similar to that recorded at planting. The linear trend for the Carbon content of Control plots to increase with increased application of Nitrogen and for treated plots to decline continued (P = 0.059; Table 1.91).

Table 1.91. Soil organic carbon at harvest

Treatment	*Nitrogen application kg/ha*				
	16	***150***	***250***	***350***	***450***
Control	*0.510*	*0.530*	*0.550*	*0.525*	*0.640*
Compost	*0.886*	*0.879*	*0.855*	*0.841*	*0.826*
lsd 5% Control vs Compost			0.135		
Control between N levels			0.169		
Compost between N levels			0.0847		

Nitrogen

Soil Total Nitrogen increased with rate of compost applied (P < 0.001; Table 1.92) and was similar to that recorded at planting.

Table 1.92. Soil nitrogen at harvest (% db)

Treatment	Lettuce
Control	0.028a*
Compost 30 m^3	0.047b
Compost 60 m^3	0.062c

* Values followed by a common subscript are not different (P > 0.05).

Nitrogen as Nitrate

Soil nitrate concentrations showed a linear increase with applied Nitrogen and there was no difference between treatments (Table 1.93).

Table 1.93. Soil Nitrogen as Nitrate (mg/kg)

	Nitrogen application kg/ha				
	16	***150***	***250***	***350***	***450***
Average of treatments	*1.40*	*2.00*	*3.85*	*6.40*	*6.55*

Ammonium

Soil Nitrogen as Ammonium was higher in plots treated with 60 m^3 of compost (Table 1.94) and the linear response of Soil Ammonium to applied Nitrogen was different for type of Compost (P = 0.006; Table 1.95). This showed Ammonium to be higher in Compost A treated plots at the lower rates of applied Nitrogen.

Table 1.94. Soil Nitrogen as Ammonium at harvest (mg/kg)

Treatment	Lettuce
Control	2.80a*
Compost 30 m^3	2.88a
Compost 60 m^3	3.98b

* Values followed by a common subscript are not different (P > 0.05).

Table 1.95. Soil Nitrogen present as ammonium at Harvest (mg/kg)

Treatment	***Nitrogen application kg/ha***				
	16	***150***	***250***	***350***	***450***
Control	*1.75*	*2.25*	*2.00*	*3.50*	*4.50*
Compost A	*2.88*	*3.75*	*3.88*	*3.12*	*4.12*
Compost B	*2.25*	*2.62*	*3.25*	*3.75*	*4.62*

lsd 5%	Control vs Composts	1.14
	Compost A v B	0.93
	Controls between Nitrogen	1.21
	Compost between Nitrogen	0.86

Growing conditions

Ideal spring growing conditions were experienced but irrigation scheduling fell below recommendations during weeks 3 and 5 (Figure 1.11).

Leaching

All treatments measured leached a similar amount of water with 34% (115 mm) of the rain (63 mm) and irrigation (278 mm) being collected in the drainage lysimeters. Evaporation was 308 mm and the apparent crop water use (rain + irrigation – drainage) was 226 mm or 73.4 per cent of evaporation.

Leachate was not analysed for nutrients.

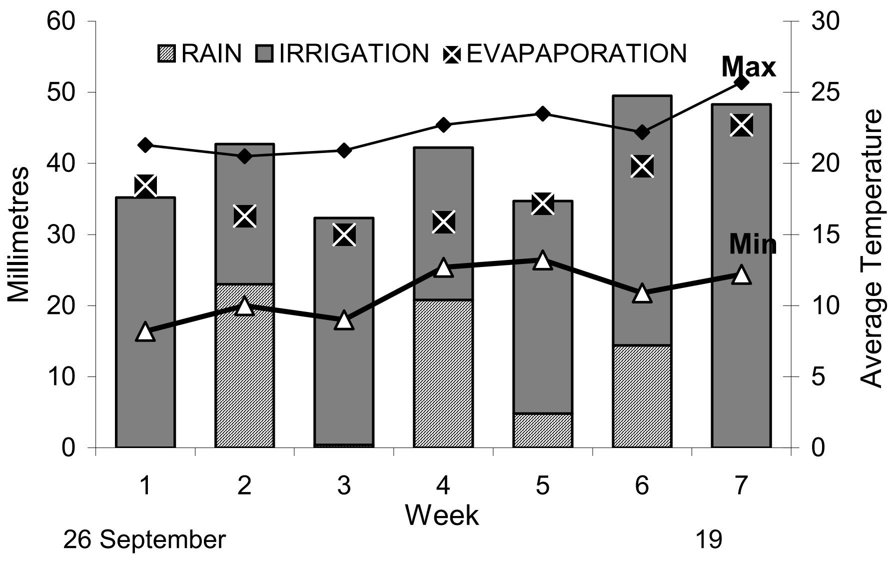


Figure 1.11. Weather conditions Lettuce Crop 5.

Discussion

While compost A met many of the analytical standards recommended it contained a high level of Nitrogen as ammonium relative to nitrate and possibly needed further processing before use (Appendix 1.1 Compost 7A). Compost B had been used as Compost A (Appendix 1.1 Compost 6A) for the final lettuce crop on the Potassium site but had been wet up and turned during its 14 week storage. Analysis showed while it had increased in ammonium content few other analysis had altered and it did not meet many of the desired criteria (Appendix 1.1 Compost 6B).

Soil analysis at planting showed low levels of soil nitrate relative to those recorded at the commencement of the previous carrot crop (Table 1.79) and while it was on average higher for plots treated with Compost A (Table 1.89) the increased levels were unlikely to impact on plant growth.

Compost application continued to increase Soil Carbon and Nitrogen but concentrations in the top 15 cm appeared to be reaching a plateau when compared to measurements made on previous crops (Tables 1.87 and 1.88).

While yield responded to applied nitrogen, compost did not alter Total or Processed Head yield (Table 1.81). However, on average, plots treated with Compost A did yield a higher percentage of processed head (Table 1.82).

Whole plant analysis showed that the nitrogen status of lettuce plants grown with compost were marginally better at low rates of applied nitrogen (Table 1.83). This showed compost was supplying low levels of plant available Nitrogen.

Carrots - Crop 6

The following compost treatments were applied and incorporated into the soil together with an application of 200 kg per hectare of double super phosphate and trace minerals one week prior to seeding carrots, variety *Stefano*, on 16 December 2002.

Treatment	Compost rates m^3/ha	Nitrogen rate kg N/ha	
Control	Nil	N1	Nil
A1/B1	30	N2	75
A2/B2	60	N3	125
		N4	225
		N5	350

Nitrogen treatments were applied as potassium and ammonium nitrate and sulphate of ammonia weekly as a percentage of the total proportional to growth by watering can together with a total of 300 kg/ha of potassium, 17 kg of magnesium and 1.5 kg of Boron. Crop growth was slowed by extremely hot weather recorded during February and the carrots were harvested at 108 days on 10 April 2003. Intermediate harvest yield was recorded on 6 March (79 days).

Compost quality

Compost A met few of the criteria considered necessary to give a positive growth response when applied to vegetable production. The C/N ratio of 27 was high and the NDI of 0.41 indicated it contained some readily available carbon. It did however contain 50 mg/L of plant available nitrate nitrogen. Compost B was the same batch as that used in the previous trial but had been matured further. The analysis report returned for this batch appeared incorrect and the correct analysis was assumed to be similar to that reported previously (Appendix 1.1 Compost 8A & 6B).

Compost	Carbon Nitrogen Ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 8A	27	0.41	74	1.1	50	> 1.0
Compost 6B	25	0.37	100	1.2	78	< 0.10

Harvest - 79 days

Plant density

There was no treatment effect on plant density. The 65 plants per m^2 recorded was lower than planned.

Total plant weight

While there were no significant difference within the main plot stratum Control, Compost A and Compost B treated plots showed a different linear response to applied Nitrogen (P = 0.025; Table 1.96). This showed that the repeated application of compost was increasing total plant growth at the low rates of applied Nitrogen, Compost A gave better total growth than Compost B and Control at low rates of Nitrogen but poorer growth at higher rates of applied Nitrogen.

Table 1.96. Total carrot plant weight at 79 days (t/ha)

Treatment	***Nitrogen application kg/ha***				
	0	***56***	***93***	***168***	***260***
Control	*5.45*	*18.75*	*25.12*	*41.20*	*41.95*
Compost A	*12.69*	*22.97*	*30.27*	*37.35*	*38.43*
Compost B	*9.71*	*19.26*	*26.69*	*39.37*	*40.57*

lsd 5%		
	Control vs Composts	6.3
	Compost A v B	5.17
	Controls between Nitrogen	6.43
	Compost A & B between N	4.54

Carrot tops

Within the main plot stratum Compost at 60 m^3 increased the weight of Carrot Top (P = 0.03; Table 1.97). The response of Top Weight for Compost A , Compost B and Control plots to applied Nitrogen was different (P = 0.03; Table 1.98).

Table 1.97. Weight of carrot top at 79 days (t/ha)

Treatment	Carrot Top
Control	9.31a*
Compost A	10.18a
Compost B	11.84b

* Values followed by a common subscript are not different (P > 0.05).

Table 1.98. Weight of carrot top at 79 days (t/ha)

Treatment	*Nitrogen application kg/ha*				
	0	*56*	*93*	*168*	*260*
Control	*1.74*	*6.14*	*8.17*	*14.30*	*16.18*
Compost A	*4.38*	*8.46*	*10.92*	*15.10*	*16.80*
Compost B	*3.71*	*6.96*	*10.34*	*15.41*	*18.01*

lsd 5%	Control vs Composts	2.15
	Compost A v B	1.76
	Controls between Nitrogen	2.33
	Compost between Nitrogen	1.64

Carrot roots

Plots treated with compost A and B and Control showed a different linear response for weight of carrot root to applied Nitrogen. Compost A reduced the weight of carrot root at high rates of applied Nitrogen (P = 0.039; Table 1.99).

Table 1.99. Weight of carrot root at 79 days (t/ha)

Treatment	*Nitrogen application kg/ha*				
	0	*56*	*93*	*168*	*260*
Control	*3.71*	*12.61*	*16.94*	*26.99*	*25.78*
Compost A	*8.31*	*14.51*	*19.34*	*22.25*	*21.63*
Compost B	*6.00*	*12.31*	*16.35*	*23.97*	*22.56*

lsd 5%	Control vs Composts	4.51
	Compost A v B	3.68
	Controls between Nitrogen	4.55
	Compost between Nitrogen	3.22

Final harvest - 108 days

Extreme temperatures were experienced during February and the crop generally looked poor. Top growth was noticeably higher in plots treated with compost and the crop was harvested at light weights to enable a final winter lettuce crop to be grown.

Total plant weight

There was an interaction between Compost type and applied Nitrogen (P = 0.015) and the linear response of Control and plots treated with Compost A and B to applied Nitrogen was different (P < 0.001; Table 1.100). This showed that Compost increased growth at low rates of applied Nitrogen but Compost A reduced Total Growth relative to Compost B and Control at high rates of applied Nitrogen.

Table 1.100. Total carrot plant weight at 108 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	75	125	225	350
Control	11.23	38.34	47.66	61.16	63.55
Compost A	27.71	45.01	53.84	59.59	56.67
Compost B	22.92	42.42	52.22	67.37	67.15

lsd 5%	Control vs Composts	10.0
	Compost A v B	8.2
	Controls between Nitrogen	10.5
	Compost A & B between Nitrogen	7.4

Carrot tops

The linear response of Carrot Top for Control and plots treated with Compost A and B to applied Nitrogen was different (P = 0.012; Table 1.101). The trend was for Compost to increase the weight of Carrot Top and Compost B grew more Top at the higher rates of applied Nitrogen.

Table 1.101. Weight of carrot top at 108 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	75	125	225	350
Control	2.82	8.13	10.28	14.52	15.51
Compost A	6.60	12.01	13.81	16.36	17.60
Compost B	5.63	11.17	13.85	18.28	19.16

Carrot roots

There was an interaction between Compost type and applied Nitrogen (P = 0.016) and the linear response of Weigh of Root to applied Nitrogen for Control and plots treated with Compost A and B was different (P < 0.001; Table 1.102). Compost B and Control grew more Carrot Root than Compost A at the highest rate of applied Nitrogen.

Table 1.102. Final harvest weight of carrots at 108 days (t/ha)

Treatment	Nitrogen application kg/ha				
	0	75	125	225	350
Control	8.41	30.21	37.38	46.63	48.04
Compost A	21.11	33.00	40.04	43.23	39.07
Compost B	17.28	31.25	38.38	49.09	47.99

lsd 5%	Control vs Composts	8.1
	Compost A v B	6.6
	Controls between Nitrogen	8.6
	Compost A & B between Nitrogen	6.1

Grade A,B Carrots

Root quality was poor and a high percentage of carrots did not meet grade A,B for root shape and size. The linear response of Grade A,B Carrots to applied Nitrogen for Control and plots treated with compost A and B was different (P = 0.018) and there was a trend for Compost B to produce more Grade A,B carrots (Table 1.103).

Table 1.103. Weight of Grade A,B carrots at 108 days (t/ha)

Treatment	*Nitrogen application kg/ha*				
	0	*75*	*125*	*225*	*350*
Control	*0.11*	*18.22*	*22.64*	*29.84*	*27.12*
Compost A	*11.73*	*18.72*	*24.77*	*29.32*	*19.72*
Compost B	*6.68*	*15.98*	*25.35*	*32.97*	*28.07*

Nitrogen, Phosphorus and Potassium content of whole plant

Nitrogen content of carrot top

While there was no difference between treatments within the main plot stratum the response of nitrogen content of Top from plants grown in Control and Treated plots showed a different quadratic response to applied Nitrogen (P = 0.045; Table 1.104). There was a trend for plants from Compost treated plots to have higher Nitrogen levels in their leaves.

Table 1.104. Nitrogen content of carrot top (% db)

Treatment	*Nitrogen application kg/ha*				
	0	*75*	*125*	*225*	*350*
Control	*1.670*	*1.588*	*1.628*	*1.715*	*2.098*
Compost	*1.685*	*1.650*	*1.716*	*1.811*	*2.000*

Phosphorus content of tops

Phosphorus content of Top was within normal range but lower (P = 0.004) in carrots grown in Compost treated Plots (Control 0.412 and Treated 0.377% db).

Potassium content of tops

Tops continued to show higher Potassium content with increased rates of applied Compost (Table 1.105).

Table 1.105. Potassium content of carrot top (% db)

Treatment	Carrot top
Control	3.408a*
Compost 30 m^3	3.507a
Compost 60 m^3	3.839b

* Values followed by a common subscript are not different (P > 0.05).

Nitrogen, Potassium and Phosphorus content of carrot root

Nitrogen

Nitrogen content of roots was higher with higher rates of applied Compost (Table 1.106).

Table 1.106. Nitrogen content of carrot root (% db)

Treatment	Carrot root
Control	1.243a*
Compost 30 m^3	1.250a
Compost 60 m^3	1.340b

* Values followed by a common subscript are not different ($P > 0.05$).

Phosphorus

Root Phosphorus content was fractionally lower in plots treated with 30 m^3 of Compost (Table 1.107).

Table 1.107. Phosphorus content of carrot root (% db)

Treatment	Carrot root
Control	0.5115a*
Compost 30 m^3	0.4985b
Compost 60 m^3	0.5195a

* Values followed by a common subscript are not different ($P > 0.05$).

Potassium

Potassium content of Carrot Root was higher at the higher rate of Compost application (Table 1.107).

Table 1.107. Potassium content of carrot root (% db)

Treatment	Carrot Root
Control	2.920a*
Compost 30 m^3	2.977a
Compost 60 m^3	3.126b

* Values followed by a common subscript are not different ($P > 0.05$).

Analysis of carrot youngest fully mature leaf at harvest

The analysis of YFML at harvest showed Compost treated plots to have lower levels of Calcium, Manganese and Zinc (Table 1.108).

Table 1.108. Analysis of carrot youngest fully mature leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range*
% db				
Phosphorous	0.350	0.348	ns	0.3–0.4
Potassium	3.560	3.653	ns	1.3–1.5
Sodium	1.088	1.221	ns	0.7–4.5
Calcium	2.115	1.871	0.166	1.8–2
Magnesium	0.382	0.386	ns	0.35–0.40
Sulphur	0.366	0.366	ns	0.3–0.6
mg/kg				
Boron	50	51	ns	29–35
Copper	6.6	7.3	0.52	5–7
Iron	678	628	ns	120–350
Manganese	47	25	4.7	190–350
Zinc	36.0	31.5	3.7	20–50

* Reuter D.J. and Robinson J.B. Plant Analysis second edition CSIRO Publishing 1997.

Soil analysis at seeding

Nitrogen

Soil Total Nitrogen in the top 15 cm appeared to have plateaued but increased with rate of applied Compost (Table 1.109).

Table 1.109. Soil total nitrogen (0-15 cm) (% db)

Treatment	%
Control	.028a*
Compost 30 m^3	.049b
Compost 60 m^3	.067c

* Values followed by a common subscript are not different (P > 0.05).

Nitrogen present as Nitrate

Within main plots Compost Type and Rate impacted on soil nitrate (Table 1.110). Soil nitrate levels of plots treated with different types of Compost showed a different response to applied Nitrogen (P = 0.021; Table 1.111). Despite its high C/N ratio Compost A increased soil levels of plant available nitrogen.

Table 1.110. Soil Nitrogen present as Nitrate at planting (mg/kg)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	6.25b*		
Compost A		9.00c	11.2d
Compost B		5.05ab	4.00a

* Values followed by a common subscript are not different (P > 0.05).

Table 1.111. Soil Nitrogen present as Nitrate at planting (mg/kg)

Treatment	*Nitrogen application kg/ha*				
	0	*75*	*125*	*225*	*350*
Control	*3.50*	*5.50*	*7.25*	*8.00*	*7.00*
Compost A	*7.00*	*9.50*	*11.88*	*11.13*	*11.00*
Compost B	*2.62*	*3.50*	*4.75*	*4.75*	*7.00*

Soil Nitrogen present as Ammonium

Soil Nitrogen present as Ammonium levels in plots treated with different types of Compost showed a different linear response to applied Nitrogen. Differences were small (P = 0.019; Table 1.112).

Table 1.112. Soil nitrogen present as Ammonium at planting (mg/kg)

Treatment	*Nitrogen application kg/ha*				
	0	*75*	*125*	*225*	*350*
Control	*1.00*	*1.00*	*1.50*	*1.00*	*1.25*
Compost A	*1.00*	*1.62*	*1.12*	*1.12*	*1.12*
Compost B	*1.00*	*1.38*	*1.12*	*1.75*	*1.62*

lsd 5%	Control vs Composts	0.59
	Compost A v B	0.48
	Controls between Nitrogen	0.70
	Compost between Nitrogen	0.49

Soil analysis at harvest

Nitrogen

Soil Total Nitrogen was similar to that recorded at planting and increased with rate of applied Compost (Table 1.109).

Soil Nitrogen present as Nitrate

Nitrogen as nitrate had fallen. It showed a linear response to applied Nitrogen, (P < 0.001), but no significant difference between treatments (Table 1.113).

Table 1.113. Soil Nitrogen present as Nitrate at harvest (mg/kg)

Treatment	*Nitrogen application kg/ha*				
	0	*75*	*125*	*225*	*350*
Control	*1.00*	*1.50*	*2.50*	*2.75*	*4.50*
Compost	*2.50*	*3.75*	*3.94*	*4.06*	*4.62*

Soil Nitrogen present as Ammonium

There was an interaction between Compost Rate and Nitrogen for Soil content of Nitrogen present as Ammonium with Compost applied at 30 m^3 giving higher concentrations than Compost applied at 60 m^3 at the lower levels of applied Nitrogen (P = 0.026; Table 1.114).

Table 1.114. Soil Nitrogen present as Nitrate at harvest (mg/kg)

Treatment	***Nitrogen application kg/ha***				
	0	***75***	***125***	***225***	***350***
Control	*2.75*	*2.75*	*3.50*	*2.75*	*5.00*
Compost 30 m^3	*3.00*	*4.12*	*3.88*	*4.25*	*4.50*
Compost 60 m^3	*3.62*	*2.00*	*2.12*	*3.75*	*3.25*

lsd 5%	Control vs Composts	1.97
	Compost 30 m^3 v 60 m^3	1.61
	Controls between Nitrogen	1.79
	Compost 30 m^3 & 60 m^3 between N	1.27

Growing conditions

Hot weather was experienced over the total growing period. Irrigation scheduling did not meet recommendations during seedling establishment and a main irrigation line failure caused the crop to dry during week 13 (Figure 1.12).

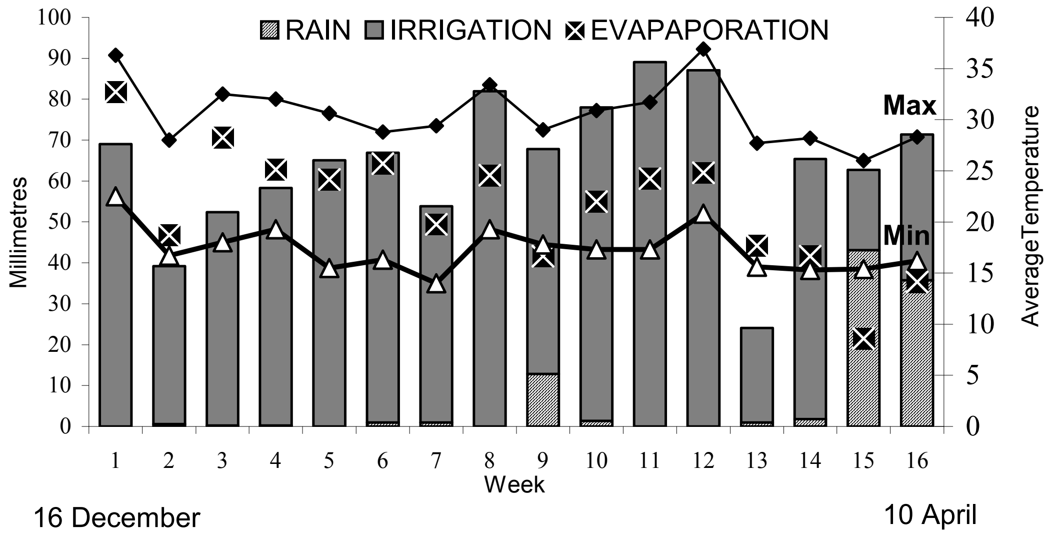


Figure 1.12. Weather conditions carrot crop 6.

Leaching

All treatments measured leached a similar amount of water with 23% (239 mm) of the rain (99 mm) and irrigation (933 mm) being collected in the drainage lysimeters. Evaporation was 859 mm and the apparent crop water use (rain + irrigation – drainage) was 793 mm or 92 per cent of evaporation.

Leachate was not analysed for nutrients.

Discussion

Despite having a C/N ratio of 27 Compost A increased levels of plant available nitrate nitrogen at seeding (Table 1.111). This resulted in increased plant growth at lower levels of applied nitrogen but reduced growth at higher levels relative to Compost B and Control at both harvests (Tables 1.96 and 1.99). Top growth of Compost treated plots was higher and the lower total plant weight was the result of poorer root growth of Compost A at the high rates of applied nitrogen. The trend was for Compost B to produce more carrot root than Control or Compost A treated plots (Tables 1.101 and 1.102). The quality of carrots from Compost treated plots was better and Compost B recorded more Grade A,B carrots (Table 1.103).

Plant analysis confirmed the better nitrogen status of plants grown in Compost treated plots (Tables 1.104 and 1.106). Compost reduced Calcium, Manganese and Zinc content of Youngest Fully Mature Leaf at harvest (Table 1.108).

The application of fresh compost stimulated the mineralisation of plant available soil nitrogen and cause increased carrot growth at lower levels of applied Nitrogen. Higher levels of applied Nitrogen decreased growth of carrots grown in Compost A treated soil by reducing root growth relative to top growth at higher levels of applied Nitrogen. Delaying the application of applied nitrogen until later in the crops growth may reduce this effect. Compost improved carrot quality and Compost B treated plots produced more Grade A,B carrots.

Lettuce - Crop 7

Iceberg lettuce seedlings, variety *Oxley*, were transplanted on 2 May 2003 and the following fertiliser treatments applied weekly by watering can for 9 weeks. The lettuce was harvested 74 days later on 15 July 2003. Intermediate growth was recorded on 29 May 2003, 27 days after transplanting.

Treatment	Compost rates m^3/ha	Nitrogen rate kg N/ha	
Control	Nil	N1	Nil
A1/B1	30	N2	150
A2/B2	60	N3	250
		N4	350
		N5	450

Phosphorus was applied at a rate of 1500 kg per hectare of double superphosphate (260 kg P) together with a complete trace element mix as a single application across the site prior to planting. All treatments received 450 kg of Potassium and 25 kg of Magnesium per hectare. The Nitrogen treatments, together with Potassium and Magnesium were applied by watering can as weekly applications. Week 1, 5; week 2, 9; week 3, 12; week 4, 12; week 5, 16; week 6, 16; week 7, 15; week 8, 10 and week 9, 5 per cent of the total Fertiliser applied.

Compost quality

Compost A had a C/N ratio of 19, contained plant available nitrogen as Nitrate and Ammonium, was toxic, (potting mix test <5.0), and contained a high level of available carbon (NDI = < 0.10). Compost B was the same batch used for the two previous trials, had been stored for 8 months and watered and turned at approximate 4-6 week intervals. The C/N ratio had reduced to 17, it contained a low level of Nitrogen as Nitrate (30 mg/L) and its NDI of 0.2 showed it still contained readily available carbon. However, it exhibited low toxicity (67) (Appendix 1.11, Compost 9A and 6B(2)).

Compost	Carbon Nitrogen Ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 9A	19	< 0.10	< 5.0	1.4	110	0.93
Compost 6B (2)	17	0.20	67	1.3	33	9.10

Harvest - 27 days

Within the main plot stratum Compost A increased plant weight relative to Control and Compost B treated plots (Table 1.115). A linear regression fitted to the plot data grouped for Compost type accounted for 74 per cent of the observed variance (P < 0.001; Figure 1.13).

Table 1.115. Weight of lettuce plants (t/ha)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	2.24c*		
Compost A		3.424b	4.703a
Compost B		2.425c	2.516c

- Values followed by a common subscript are not different (P > 0.05).

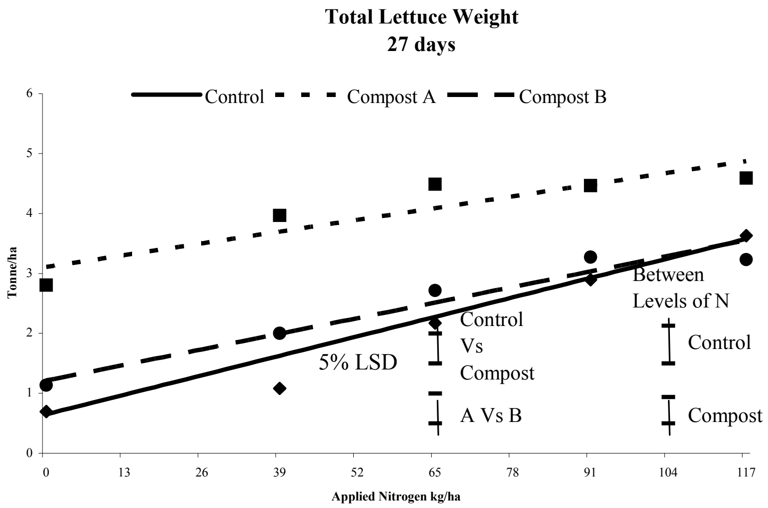


Figure 1.13. Total lettuce plant weight in response to nitrogen application at day 28.

Final harvest - 74 days

Within the main plot stratum there was an interaction between Compost type and rate. Compost A at 30 m^3 produced more total Lettuce than Compost B or Control and had a higher production at 60 m^3 (Table 1.116).

Table 1.116. Final harvested weight of lettuce (t/ha)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	45.24c*		
Compost A		52.24b	58.51a
Compost B		49.49c	45.27c

* Values followed by a common subscript are not different (P > 0.05).

Percentage head

The linear response of Compost A to applied Nitrogen for Percentage Head was different (P < 0.001; Table 1.117). Plots treated with Compost A produced a higher percentage of processed head than Control or Compost B treated plots at most levels of applied Nitrogen.

Table 1.117. Lettuce head weight expressed as percentage of the harvested plant

Treatment	*Nitrogen application kg/ha*				
	16	***150***	***250***	***350***	***450***
Control	*0*	*33.2*	*37.5*	*42.6*	*43.4*
Compost A	*20.1*	*44.8*	*47.3*	*46.1*	*45.8*
Compost B	*0*	*37.3*	*37.6*	*39.6*	*42.5*

lsd 5%		
	Control vs Composts	5.3
	Compost A v B	4.3
	Controls between Nitrogen	5.6
	Compost A & B between Nitrogen	4.0

Total head

The higher plant weight and better percentage of processed head meant the compost showed a different quadratic response to applied Nitrogen (P = 0.014). Exponential curves fitted to the plot data had a probability of P < 0.001 and accounted for 86.7 per cent of the observed variance (Figure 1.14). The amount of processed head produced was described by the functions:

Control = $29.35-31.99\ (0.99475)^{\wedge Nitrogen}$
Compost A = $31.68 - 32.18\ (0.9887)^{\wedge Nitrogen}$
Compost B = $26.85 - 29.88\ (0.99294)^{\wedge Nitrogen}$

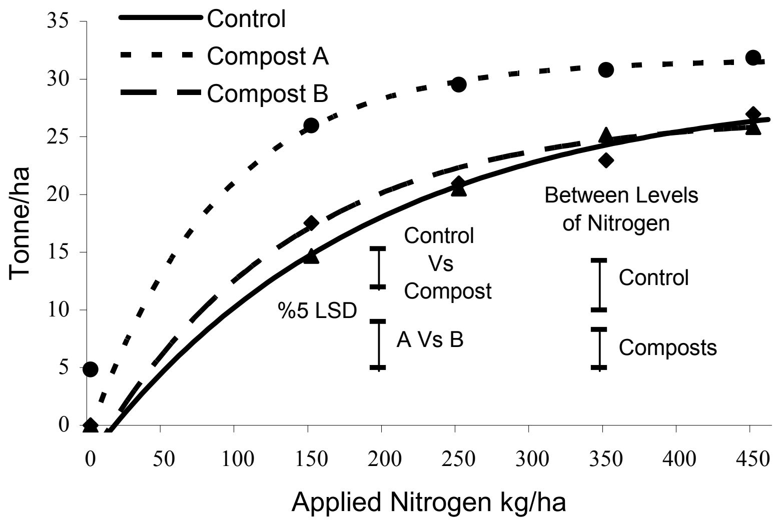


Figure 1.14. Weight of processed lettuce head.

Nitrogen, Phosphorus and Potassium content of whole plant

Nitrogen

Nitrogen content of whole plant increased with rate of applied nitrogen (Table 1.118) and within the main plot stratum plants grown in plots treated with compost contained more (2.93% db) nitrogen than plants grown in control plots (2.81%). No other differences were recorded.

Table 1.118. Nitrogen content of whole lettuce plant (% db)

Treatment	***Nitrogen application kg/ha***				
	16	***150***	***250***	***350***	***450***
Control	*1.54*	*2.43*	*3.00*	*3.35*	*3.74*
Compost	*1.65*	*2.65*	*3.13*	*3.49*	*3.72*

Phosphorus

The phosphorus content of plants grown in control plots and plots treated with compost showed a different linear response (P = 0.006) to applied nitrogen (Table 1.119).

Table 1.119. Phosphorus content of whole plant (% db)

Treatment	***Nitrogen application kg/ha***				
	16	***150***	***250***	***350***	***450***
Control	*0.47*	*0.63*	*0.74*	*0.78*	*0.79*
Compost	*0.54*	*0.66*	*0.70*	*0.73*	*0.78*

lsd 5%	Control vs Compost	0.060
	Control between N levels	0.067
	Compost between N levels	0.034

Potassium

Within the main plot stratum potassium content of whole plant increased with rate of applied compost (Table 1.120).

Table 1.120. Potassium content of whole plant (% db)

Treatment	Lettuce
Control	6.31a*
Compost 30 m^3	6.72b
Compost 60 m^3	7.10c

* Values followed by a common subscript are not different (P > 0.05).

Analysis of youngest fully mature leaf at harvest

Analysis of youngest fully mature leaf at harvest showed compost increased calcium, but lowered Manganese, Molybdenum and Zinc concentration (Table 1.121).

Table 1.121. Analysis of lettuce wrapper leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range**
% db				
Phosphorous	0.70	0.69	Ns	0.55–0.65
Potassium	> 0.4	> 0.4		5.5–6.0
Sodium	0.30	0.29	Ns	< 0.5–1.0
Calcium	0.80	0.89	0.07	1.4–2.0
Magnesium	0.23	0.24	Ns	0.3–0.7
Sulphur	0.24	0.25	Ns	0.3–0.32
mg/kg				
Boron	23.8	24.6	Ns	25–55
Copper	6.8	6.6	Ns	10–18
Iron	322	364	Ns	50–500
Manganese	46	20	3.6	50–300
Molybdenum	7.6	3.9	0.8	0.08–0.17
Zinc	72	55	10	30–100

* lsd - Least significant difference P = 0.05.
** Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.

Manganese and zinc concentrations continued to be low in plants grown in plots treated with compost.

Soil analysis at planting

Organic carbon

Within the main plot stratum soil carbon increased with rate of compost applied (Table 1.122).

Table 1.122. Soil organic carbon at planting (% db)

Treatment	Lettuce
Control	0.513a*
Compost 30 m^3	0.753b
Compost 60 m^3	0.918c

* Values followed by a common subscript are not different (P > 0.05).

Nitrogen

Within the main plot stratum soil nitrogen increased with increased rate of compost application (Table 1.123).

Table 1.123. Soil Nitrogen at planting (% db)

Treatment	Lettuce
Control	0.028a*
Compost 30 m^3	0.048b
Compost 60 m^3	0.066c

* Values followed by a common subscript are not different (P > 0.05).

Soil nitrogen content of control and compost treated plots showed a different linear response to applied nitrogen (P = 0.02) and linear regressions fitted to the plot data grouped for compost rate accounted for 86.4 per cent of the observed variance (P < 0.001; Figure 1.15). Soil nitrogen for each rate of applied compost was described by the functions:

Control = 0.0246 + 0.00001358 x applied nitrogen
30 m^3 = 0.0476 + 0.00001148 x applied nitrogen
60 m^3 = 0.0683 – 0.00001012 x applied nitrogen

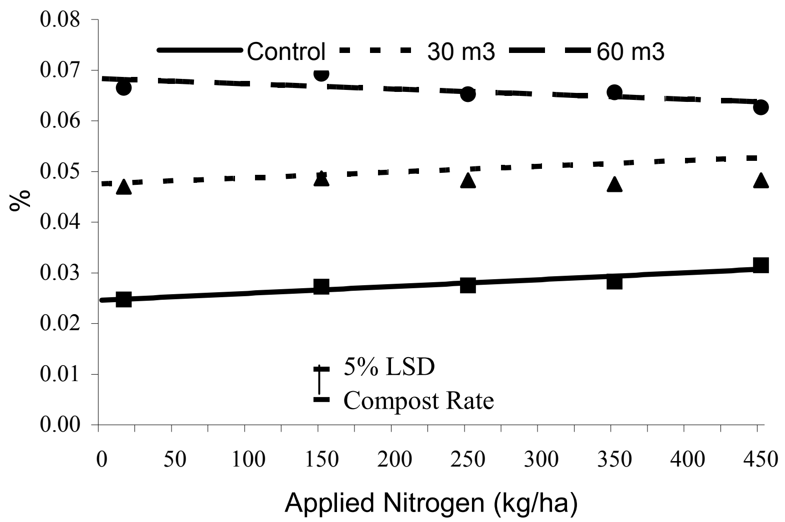


Figure 1.15. Soil nitrogen content at seeding.

While control, and plots treated with 30 cubic metres of compost, showed a slight increase in soil nitrogen with increasing application of nitrogen fertiliser, there was a trend for plots treated with 60 cubic metres to decline in soil nitrogen with higher rates of fertiliser application.

Nitrogen as Nitrate

The level of soil nitrogen present as nitrate was effected by both compost type and rate ($P < 0.001$; Table 1.124). The application of fresh compost dramatically increased soil nitrate. Control plots and those treated with the matured compost B were not different.

Table 1.124. Soil Nitrogen as Nitrate at planting (% db)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	2.8a*		
Compost A		14.15b	24.45c
Compost B		3.90a	4.15a

* Values followed by a common subscript are not different ($P > 0.05$).

Nitrogen as Ammonium

Soil ammonium was increased by compost A applied at the 60 m^3. There was no difference between other treatments (Table $P = 0.001$).

Table 1.124. Soil Nitrogen as Ammonium planting (% db)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	3.35a*		
Compost A		4.05a	8.05b
Compost B		2.60a	3.20a

* Values followed by a common subscript are not different ($P > 0.05$).

Soil analysis at harvest

Organic Carbon

Within the main plot stratum soil carbon increased with rate of compost applied (Table 1.125) and was similar to that recorded at planting.

Table 1.125. Soil Carbon at harvest (% db)

Treatment	
Control	0.535a*
Compost 30 m^3	0.789b
Compost 60 m^3	0.952c

* Values followed by a common subscript are not different ($P > 0.05$).

Nitrogen

Soil nitrogen increased with rate of applied compost (P < 0.001; Table 1.126).

Table 1.126. Soil Nitrogen at harvest (% db)

Treatment	
Control	0.028a*
Compost 30 m^3	0.048b
Compost 60 m^3	0.065c

* Values followed by a common subscript are not different (P > 0.05).

Nitrogen as nitrate

Nitrogen present as nitrate had fallen dramatically but within the main plot stratum plots treated with 60 m^3 of compost still recorded higher levels (P = 0.04; Table 1.127).

Table 1.127. Soil Nitrogen present as Nitrate at harvest (mg/ kg)

Treatment	
Control	3.90a*
Compost 30 m^3	4.08a
Compost 60 m^3	5.23b

* Values followed by a common subscript are not different (P > 0.05).

Nitrogen as Ammonium

While levels of soil ammonium were lower than at planting (Table ?) plots treated with 60 m^3 of the fresh compost (A) still recorded higher levels (P = 0.03; Table 1.128).

Table 1.128. Soil Nitrogen as Ammonium at harvest (% db)

Treatment	Compost		
	Nil	**30 m^3**	**60 m^3**
Control	1.24a*		
Compost A		1.23a	2.00b
Compost B		1.15a	1.40a

* Values followed by a common subscript are not different (P > 0.05).

Nutrient leaching

All treatments measured leached a similar amount of water with 78% (389 mm) of the rain (364 mm) and irrigation (133 mm) being collected in the drainage lysimeters. Evaporation was 153 mm and the apparent crop water use (rain + irrigation – drainage) was 110 mm or 72 per cent of evaporation.

Nitrogen leached during the trial is shown in Table 1.129.

Table 1.129. Nitrogen collected in drainage lysimeters during crop growth

Compost	Rate m^3/ha	Applied nitrogen kg/ha	Total nitrogen kg/ha	N as NH_4 kg/ha	N as NO_3 kg/ha	Organic N kg/ha
Control	0	0	28a	2.4	25a	0.5
Control	0	250	84b	3.9	79a	0.7
A	30	250	103b	0.9	100a	1.8
B	30	250	83b	1.3	80a	1.3
A	60	250	104b	2.7	83a	18.4
B	60	250	86b	1.6	84a	1.1
A	60	450	261c	0.4	266b	-5.4
B	60	450	228c	0.2	221b	6.6

* Values followed by a common subscript are not different (P > 0.05). Values are the mean of 3 replicates.

Separate analysis of plots fertilised with 250 kg of nitrogen showed that on average Compost A increased the amount of Nitrogen leached (104 kg/ha) when compared to Control (84 kg/ha) and Compost B (83 kg/ha) treated plots (P = 0.07). Plots fertilised with 450 kg of nitrogen leached more nitrogen.

Growing conditions

Typical cold winter growing conditions were experienced (Figure 1.16).

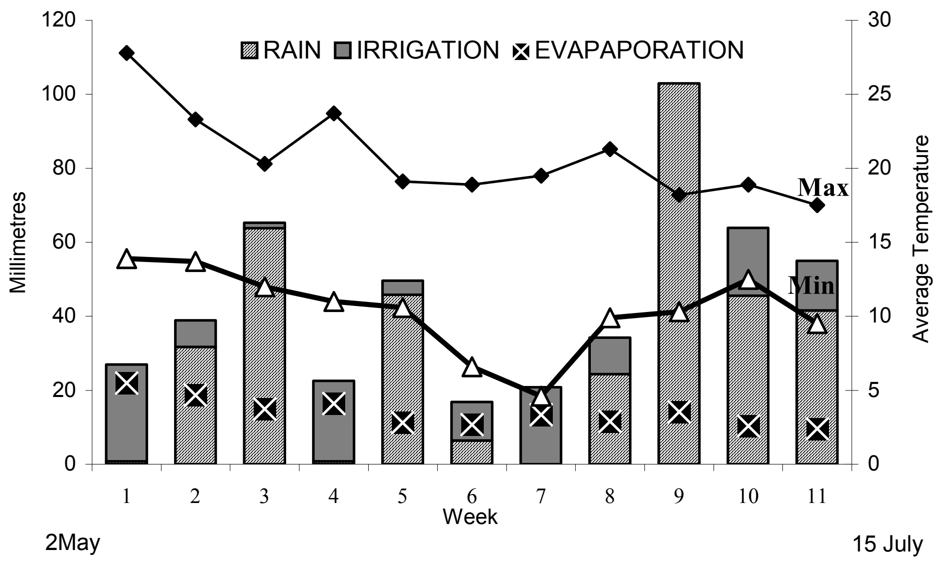


Figure 1.16. Growing conditions for Lettuce Crop 7.

Discussion

On analysis Compost A recorded a C/N ratio of 19, and contained both Nitrate and Ammonium nitrogen. It was not mature, exhibited toxicity and contained readily available carbon (Appendix 1.11 Compost 9A). It stimulated soil content of plant available nitrate at planting (Table 1.124) and increased plant growth at both harvests (Figure 1.13 and Table 1.116). It increased the percentage of plant recovered as processed head and increased weight of processed head dramatically (Table 1.117 and Figure 1.14).

Plant analysis confirmed increased nitrogen content of plants grown in Compost treated plots (Table 1.118). Potassium content was increased with increased rate of Compost application (Table 1.120). Compost lowered Manganese and Zinc content of youngest fully mature wrapper leaf at harvest (Table 1.121).

Soil Carbon and Nitrogen in the top 15 cm had reached a plateau. Soil Nitrogen content for plots treated with 60 m^3 of compost declined with increased rates of applied Nitrogen but Soil Nitrogen increased with applied Nitrogen in Control and plots treated with 30 m^3 of Compost (Figure 1.15).

The application of fresh Compost stimulated the mineralisation of soil nitrogen and increased plant available nitrate and ammonium. This increased plant growth and caused a higher yield of lettuce at lower levels of applied Nitrogen.

Conclusion and trial summaries – Nitrogen site

At the commencement of the trials Compost quality was poor and although it improved as the work progressed the majority of batches failed to meet the analysis criteria considered necessary to give an immediate response in vegetable production. Despite this increased growth was recorded in 3 of the 4 lettuce crops grown on this site.

The increased growth recorded for compost treated plots in the first lettuce crop (crop 1) was attributed to better Potassium rather than Nitrogen nutrition of the crop. Compost A applied to the second lettuce crop (crop 3) stimulated soil nitrate and contributed to the average of the Compost treatments showing about 10 per cent better growth than Controls. Compost A used on the third lettuce crop (crop 5) was poorly processed, failed to increase soil nitrate at planting and reduced plant nitrogen content. Harvest weights were similar to controls. Compost A applied to the final lettuce crop (crop 7), while still relatively immature, contained plant available nitrate, stimulated soil nitrate production, increased the nitrogen status of plants and increased production by as much as 20 per cent.

The regression of plot data for average weight of lettuce at harvest and soil nitrate concentration at planting, grouped for rate of applied nitrogen, accounted for 90 percent of the observed variance and demonstrated the impact soil nitrate concentration had on final yield (Figure 1.17).

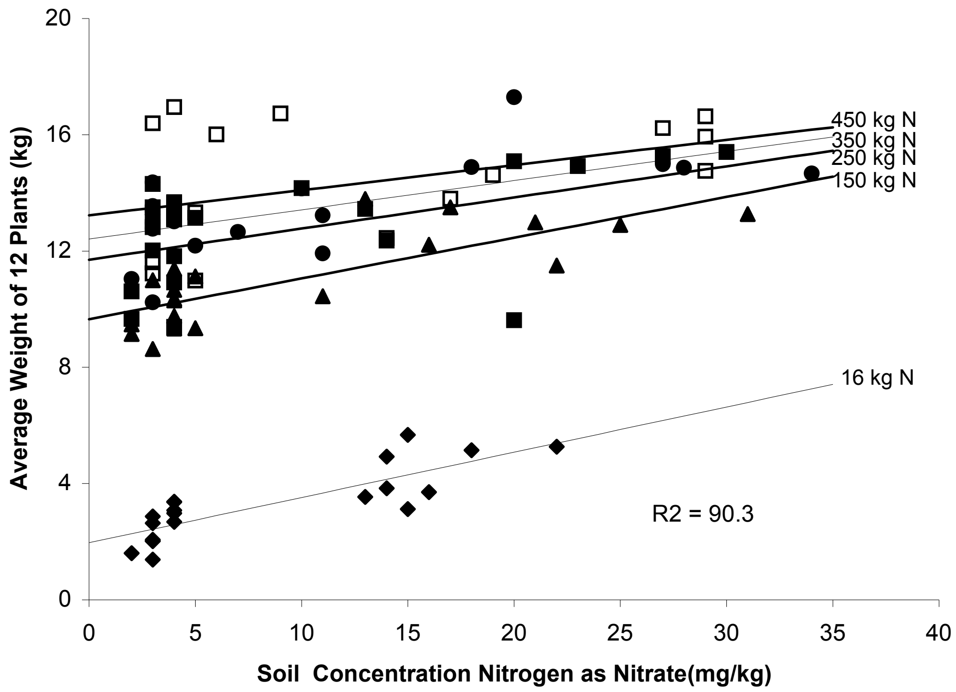


Figure 1.17 Effect of soil concentration of nitrate nitrogen on final weight of lettuce.

Carrots are more sensitive to Compost quality and Compost which does not meet the suggested critical analysis values will potentially reduce yields. Carrots showed increased vigour and top growth in response to higher levels of nitrate and soil organic nitrogen resulting from the repeated use of Compost. Increased root yields at high rates of Nitrogen application were recorded at interim harvests but these were not significant at final harvest. The control of vigour and timing of Nitrogen application is obviously important in achieving optimum root yield at a particular rate of Nitrogen application. The delaying of nitrogen application to compost treated plots to reduce vigour and achieve a better balance between shoot and root growth would potentially increase root yield at lower rates of applied Nitrogen. Compost consistently improved carrot quality and increased the weight of grade A,B carrots.

Poor compost quality reduced both top and root weight of the first carrot crop (crop 2) but Compost increased the percentage of grade A,B carrots. The quality of Compost A applied to the second carrot crop (crop 4) was poor and reduced top and root growth at 75 days. Compost B increased root growth at 75 days but differences between Compost type were not significant at harvest and on average Compost reduced root growth at higher rates of Nitrogen application. However, Compost improved root quality and produced more Grade A,B carrots. Compost quality for the third carrot crop (crop 6) was better and despite a C/N ratio of 27 Compost A increased soil nitrate and increased top and root growth at low rates of applied Nitrogen but root growth at high rates of Nitrogen was reduced. Compost B showed increased top weight at all rates of applied Nitrogen and root weight similar to Controls. Root quality was improved and Compost B produced more grade A,B carrots.

Compost reduced the plant availability of Manganese and Zinc and increased applications of these trace minerals may be necessary in some areas.

Results - Phosphorus replacement trial site

Carrots - Crop 1

The following fertiliser and compost treatments were applied and incorporated into the soil one week prior to seeding Carrots, variety *Stefano*, on 3 May 2001.

Treatment	Compost rates m^3/ha	Phosphorus rate kg N/ha	
Control	Nil	P1	Nil
A1/B1	30	P2	50
A2/B2	60	P3	125
		P4	200
		P5	275

In addition all plots received a total of 340 kg of Nitrogen, 306 kg of Potassium, 18 kg of Magnesium and 1.8 kg of Boron applied weekly through the sprinkler system. Weekly amounts were a percentage of the total proportional to growth. The carrots were harvested at 159 days on 9 October. Intermediate harvest weights were recorded on 17 July (74 days) and 28 August 9 (116 days).

Compost quality

The same composts as those used for the first trial on the Nitrogen site were used.

Compost A failed to meet many of the criteria desired. It's carbon to nitrogen ratio of 28 was high, it contained no plant available Nitrogen and the nitrogen drawdown index of 0.21 indicated it still contained readily available carbon. Although Compost B had been heaped and stored for about 9 months after its initial 'thermophilic' composting period it was similar to compost A. However, it's carbon to nitrogen ratio, 21, was lower, it contained more than twice as much Phosphorus and the Nitrogen Drawdown index of 0.50 was acceptable (Compost 1A and B).

Compost	Carbon Nitrogen Ratio	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 1A	28	0.21	55	1.3	< 1.0	< 0.1
Compost B	21	0.50	57	1.5	< 1.0	< 0.1

Plant weight 74 days

Within the main plot stratum Total Plant growth increased when 60 m^3 of Compost was applied ($P = 0.004$; Table 1.130).

Table 1.130. Total plant weight at 74 days (t/ha)

Treatment	Carrot
Control	5.43a*
Compost 30 m^3	5.62a
Compost 60 m^3	8.11b

* Values followed by a common subscript are not different ($P > 0.05$).

There was an interaction between Compost type and applied Phosphorus (P = 0.027) and the quadratic response of Plant weight to applied Nitrogen for different Compost type was different (P = 0.035; Table 1.131). This was consistent with Compost supplying plant available Phosphorus and Compost B containing 1.3% Phosphorus and Compost A 0.6% (db).

Table 1.131. Total plant weight at 74 days (t/ha)

Treatment	Phosphorus application kg/ha				
	0	50	125	200	250
Control	0.41	4.98	6.58	7.51	7.65
Compost A	2.29	6.62	7.68	8.74	8.58
Compost B	4.62	6.99	7.94	7.81	8.88
lsd 5%	*Control vs Composts*		*2.16*		
	Compost A v B		*1.77*		
	Controls between Phosphorus		*1.93*		
	Compost between Phosphorus		*1.36*		

The ratio of root to shoot produced was consistent across main plots and similar relationships to that of whole plant were found for weight of root. Root weight increased with weight of compost (Table 1.132) and there was an interaction between Compost type and applied Nitrogen (P = 0.014). The quadratic response of root weight to applied Phosphorus for each Compost type was different with Compost B producing more root weight (P = 0.023; Table 1.133).

Table 1.132. Weight of carrot root at 74 days (t/ha)

Treatment	Carrot
Control	2.75a*
Compost 30 m^3	3.09a
Compost 60 m^3	4.08b

* Values followed by a common subscript are not different (P > 0.05).

Table 1.133. Weight of carrot root at 74 days (t/ha)

Treatment	Phosphorus application kg/ha				
	0	50	125	200	250
Control	0.26	2.54	3.17	3.97	3.82
Compost A	1.27	3.25	3.89	4.46	4.47
Compost B	2.36	3.53	3.98	4.04	4.62
lsd 5%	*Control vs Composts*		*0.97*		
	Compost A v B		*0.79*		
	Controls between Phosphorus		*0.84*		
	Compost between Phosphorus		*0.59*		

Total plant at final harvest 159 days

Shade from tall trees north of the experimental plots became apparent as day length decreased in June and all plots were scored for shading over the period 8.00 a.m. to 4.00 p.m. This was used as a covariate in the analysis of the final harvest (P < 0.001).

Within the main plot stratum Compost treated plots (109 t/ha) produced more Total Plant weight than Controls (97 t/ha) ($P < 0.001$). There was an interaction between Compost type and rate of applied Phosphorus ($P = 0.003$) and the linear and quadratic responses of Total plant weight to applied Phosphorus for Compost type were different ($P = 0.004$ and $P = 0.044$; Table 1.134).

Table 1.134. Total weight of carrot plant at harvest (t/ha)

Treatment	Phosphorus application kg/ha				
	0	50	125	200	250
Control	45.1*	98.4	109.0	119.7	113.0
Compost A	81.6	107.5	113.3	118.0	117.0
Compost B	97.1	108.2	117.5	115.6	118.2

lsd 5%	*Control vs Composts*	*9.38*
	Compost A v B	*7.66*
	Controls between Phosphorus	*9.36*
	Compost between Phosphorus	*6.62*

* Treatment means adjusted for covariate.

Weight of Top at 159 days

There was an interaction between treated and untreated plots and applied phosphorus ($P = 0.023$). The response of Weight of Carrot Top to applied Phosphorus for Control and Compost treated plots was different ($P = 0.023$; Table 1.135). Compost treated plots produced more Top.

Table 1.135. Weight of carrot top at harvest (t/ha)

Treatment	Phosphorus application kg/ha				
	0	50	125	200	250
Control	7.4	14.2	17.6	17.8	17.6
Compost	13.2	15.7	17.7	18.0	18.9

lsd 5%	*Control vs Compost*	*3.2*
lsd 5%	*Control between N levels*	*3.4*
lsd 5%	*Compost between N levels*	*1.7*

The linear response of plant top to applied Phosphorus was different for type of Compost applied and there was a trend for Compost A to produce more top at the higher rates of applied Phosphorus ($P = 0.013$; Table 1.136).

Table 1.136. Weight of carrot top at harvest (t/ha)

Treatment	Phosphorus application kg/ha				
	0	50	125	200	250
Control	7.4	14.2	17.6	17.8	17.6
Compost A	12.0	15.4	17.4	19.2	19.5
Compost B	14.3	15.9	17.9	16.8	18.4

lsd 5%	*Control vs Composts*	*3.6*
	Compost A v B	*2.9*
	Controls between Phosphorus	*3.4*
	Compost between Phosphorus	*2.4*

* Treatment means adjusted for covariate.

Total weight of carrot root

Within the main plot stratum total root weight was affected by Compost type ($P = 0.034$; Table 1.137).

Table 1.137. Total carrot roots at harvest (t/ha)

Treatment	Carrot
Control	82.1a*
Compost A	90.7b
Compost B	94.6c

* Values followed by a different subscript are different ($P < 0.05$).

There was an interaction between Compost Type and applied Phosphorus ($P = 0.008$) and the response of weight of roots harvested to applied phosphorus was different with a trend for Compost B to produce more carrots at the lower rates of applied Phosphorus ($P < 0.018$; Table 1.138).

Table 1.138. Weight of carrot root at harvest (t/ha)

Treatment	Phosphorus application kg/ha				
	0	50	125	200	250
Control	37.7	84.2	91.4	101.9	95.4
Compost A	69.5	92.0	95.9	98.8	97.5
Compost B	82.8	92.3	99.5	98.7	99.8

lsd 5%	*Control vs Composts*	*7.3*
	Compost A v B	*6.0*
	Controls between Phosphorus	*7.8*
	Compost between Phosphorus	*5.5*

An exponential curve fitted to the treatment means gave a probability of $P < 0.001$ and accounted for 90.8 per cent of the variance (Figure 1.10). The relationship of total weight of carrots produced at harvest and applied phosphorus was described by the functions.

Control = $97.31 – 59.34 (0.97237)^{\wedge Phosphorus}$
Compost A = $97.90 – 28.14 (0.97237)^{\wedge Phosphorus}$
Compost B = $98.9 – 16.69 (0.97237)^{\wedge Phosphorus}$

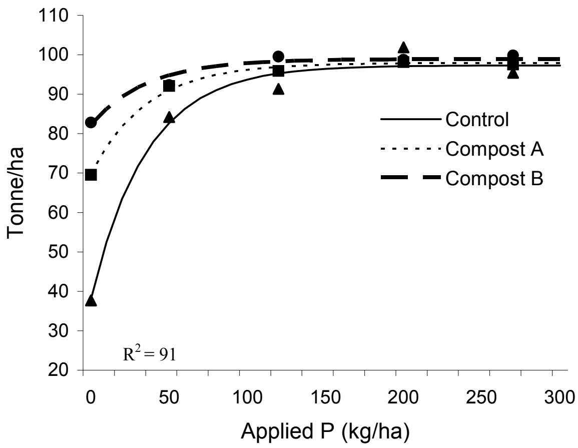


Figure 1.17. Total weight of carrot root harvested at 159 days.

The rate of applied Phosphorus to achieve 99 per cent of maximum yield was 146.7 kg/ha for the control, 119.9 kg/ha for Compost A and 100.8 kg/ha for compost B. This approximated that 40 per cent of the phosphorus contained in the compost could be substituted for applied Phosphorus. There was a small additional growth benefit from the addition of compost.

Market A,B grade carrots

Carrot quality was similar and there was an interaction between rate of applied Compost and applied Phosphorus (P = 0.032; Table 1.139) for weight of Grade A,B carrots which showed more market sized carrots were produced at the low levels of applied Phosphorus.

Table 1.139. Weight of grade A,B carrots (t/ha)

Treatment	*Phosphorus application kg/ha*				
	0	*50*	*125*	*200*	*250*
Control	*14.6*	*47.2*	*55.5*	*65.5*	*57.9*
Compost 30 m³	*34.0*	*60.0*	*59.7*	*58.9*	*62.6*
Compost 60 m³	*52.3*	*61.5*	*67.5*	*67.2*	*56.6*

lsd 5%	Control vs Composts	16.3
	Compost A v B	13.3
	Controls between Phosphorus	16.2
	Compost between Phosphorus	11.6

Nitrogen, phosphorus and potassium content at harvest

Nitrogen content of carrot top

Within the main plot stratum carrot leaf Nitrogen declined with rate of Compost applied (P = 0.056; Table 1.140) but the response of leaf nitrogen concentration to applied Phosphorus was not different for Control and Compost treated plots Table (1.141). The nitrogen status of plants was generally good and reflected the high level of Nitrogen fertiliser used to remove any likely response to the Nitrogen contained in the Compost.

Table 1.140. Nitrogen content of carrot top at harvest (% db)

Treatment	Carrot
Control	2.14a*
Compost 30 m^3	1.95b
Compost 60 m^3	1.84c

* Values followed by a different subscript are different (P < 0.05).

Table 1.141. Response of leaf nitrogen content to applied phosphorus

Treatment	***Phosphorus application kg/ha***				
	0	***50***	***125***	***200***	***250***
Control	*2.45*	*2.19*	*2.08*	*2.02*	*1.98*
Compost	*2.07*	*1.96*	*1.82*	*1.83*	*1.80*

Phosphorus content of Carrot Top

Within main plots Compost B gave higher Phosphorus content of Carrot Top (Table 1.142). This was consistent with its P content of 1.3 per cent compared to Compost A, 0.6 per cent.

Table 1.142. Phosphorus content of carrot top at harvest (% db)

Treatment	%
Control	0.214a*
Compost A	0.217a
Compost B	0.226b

* Values followed by a similar subscript are not different (P > 0.05).

The linear response of Phosphorus content of carrot leaf to applied phosphorus was different for each rate of applied Compost (P = 0.018; Table 1.143). Phosphorus content was below the 0.32 per cent reported by McPharlin *et al.* and production results showed that yield was maximised at contents above 0.21 per cent db.

Table 1.143. Phosphorus content of carrot top at harvest (% db)

Treatment	***Phosphorus application kg/ha***				
	0	***50***	***125***	***200***	***250***
Control	*0.158*	*0.170*	*0.195*	*0.252*	*0.295*
Compost 30 m^3	*0.161*	*0.175*	*0.211*	*0.261*	*0.309*
Compost 60 m^3	*0.170*	*0.176*	*0.211*	*0.259*	*0.282*

lsd 5%		
lsd 5%	Control vs Composts	0.022
	Compost A v B	0.018
	Controls between Phosphorus	0.027
	Compost between Phosphorus	0.019

Potassium content of carrot top

There was an interaction (P = 0.012) between rate of Compost applied and applied Phosphorus for Potassium content of leaf. Potassium content was elevated in plants grown in control plots receiving no applied Phosphorus. The quadratic response of leaf Potassium content to applied Phosphorus was different for each rate of Compost (P = 0.02; Table 1.144). Compost increased leaf Potassium.

Table 1.144. Potassium content of carrot top at harvest (% db)

Treatment	***Phosphorus application kg/ha***				
	0	***50***	***125***	***200***	***250***
Control	*4.72*	*2.43*	*2.44*	*2.32*	*2.09*
Compost 30 m^3	*3.33*	*2.55*	*2.48*	*2.43*	*2.47*
Compost 60 m^3	*2.74*	*2.78*	*2.78*	*2.45*	*2.59*

lsd 5%	Control vs Composts	0.48
	Compost A v B	0.40
	Controls between Phosphorus	0.53
	Compost between Phosphorus	0.37

Nitrogen content of carrot root

There was no treatment effect on the nitrogen content of Carrot roots and an average of 1.3 per cent (db) was recorded.

Phosphorus content of carrot root

The response of Phosphorus content of root to applied Phosphorus was different for each rate of Compost applied (P = 0.001; Table 1.145) and the interaction between Compost rate and applied Phosphorus was significant (P = 0.003). Production data shows Phosphorus content above 0.320 per cent db were adequate for maximum yield.

Table 1.145. Phosphorus content of carrot root at harvest (% db)

Treatment	***Phosphorus application kg/ha***				
	0	***50***	***125***	***200***	***250***
Control	*0.168*	*0.215*	*0.292*	*0.375*	*0.375*
Compost 30 m^3	*0.196*	*0.242*	*0.331*	*0.355*	*0.371*
Compost 60 m^3	*0.235*	*0.263*	*0.320*	*0.349*	*0.369*

Lsd 5%	Control vs Composts	0.029
	Compost A v B	0.024
	Controls between Phosphorus	0.028
	Compost between Phosphorus	0.020

Potassium content of carrot root

Compost increased Potassium content of root and the linear response of Potassium content to applied Phosphorus for different rates of Compost was different (P = 0.057; Table 1.146).

Table 1.146. Potassium content of carrot root at harvest (% db)

Treatment	*Phosphorus application kg/ha*				
	0	*50*	*125*	*200*	*250*
Control	*2.46*	*1.77*	*1.58*	*1.55*	*1.59*
Compost 30 m^3	*2.02*	*1.87*	*1.74*	*1.72*	*1.72*
Compost 60 m^3	*1.90*	*1.85*	*1.85*	*1.86*	*1.79*

lsd 5%	Control vs Composts	0.225
	Compost A v B	0.184
	Controls between Phosphorus	0.240
	Compost between Phosphorus	0.170

Analysis of youngest fully mature wrapper leaf at harvest

YFML analysis is given in Table 1.147. Surprisingly the leaf analysis did not detect any treatment differences for Phosphorus content. Compost reduced Copper, Manganese and Zinc concentrations but elevated Calcium and Magnesium.

Table 1.147. Analysis of carrot wrapper leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range*
% db				
Phosphorus	0.22	0.22	ns	0.3–0.4
Potassium	na**	na		1.3–1.5
Sodium	1.57	1.62	ns	0.7–4.5
Calcium	1.61	1.78	0.14	1.8–2
Magnesium	0.27	.03	.02	0.35–0.40
Sulphur	0.28	0.24	0.02	0.3–0.6
mg/kg				
Boron	37	37	ns	29–35
Copper	5.1	3.8	0.4	5–7
Iron	862	859	ns	120–350
Manganese	138	64	23	190–350
Zinc	32	22	4.3	20-50

* Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.
** Some samples exceeded 3.0 per cent the limit of analysis.

Soil analysis

Plant available phosphorus at seeding

Natural variation within the soil and Compost, and inherent errors in experimental procedure, sampling and analysis meant that difference in soil Bicarbonate extractable Phosphorus content between some treatments could not be statistically verified (Table 1.148).

Table 1.148. Bicarbonate P content of soil at seeding (mg/kg db)

Treatment	***Phosphorus application kg/ha***				
	0	***50***	***125***	***200***	***275***
Control	*10.3*	*31.3*	*74.8*	*108*	*155*
Compost A 30 m^3	*17.5*	*36.2*	*73.5*	*125.0*	*167.5*
Compost A 60 m^3	*26.8*	*42.5*	*76.0*	*117.5*	*155.0*
Compost B 30 m^3	*23.7*	*43.8*	*77.0*	*125.0*	*141.6*
Compost B 60 m^3	*36.5*	*59.8*	*103.2*	*117.5*	*180.0*
lsd 5%	All comparisons		19.4		
	Within main plots		18.8		

The Phosphorus applied with the compost was clearly contributing to soil plant available Phosphorus.

An exponential regression fitted to the plot data to determine the relationship of total weight of carrot root harvested and soil content of Bic P at planting ($P < 0.001$) and grouped for rate of applied Compost accounted for 69 per cent of the variance. The trend was for yield to be higher at each level of soil Bic P for different rates of applied Compost ($P = 0.049$; Figure 1.18).

The weight of carrot root produced was described by the functions:

Control = 93.82 – 121.7 (0.93001)^Bic P
Compost 30 m^3 = 97.11 – 121.7 (0.93001)^Bic P
Compost 60 m^3 = 100.9 – 121.7 (0.93001)^Bic P

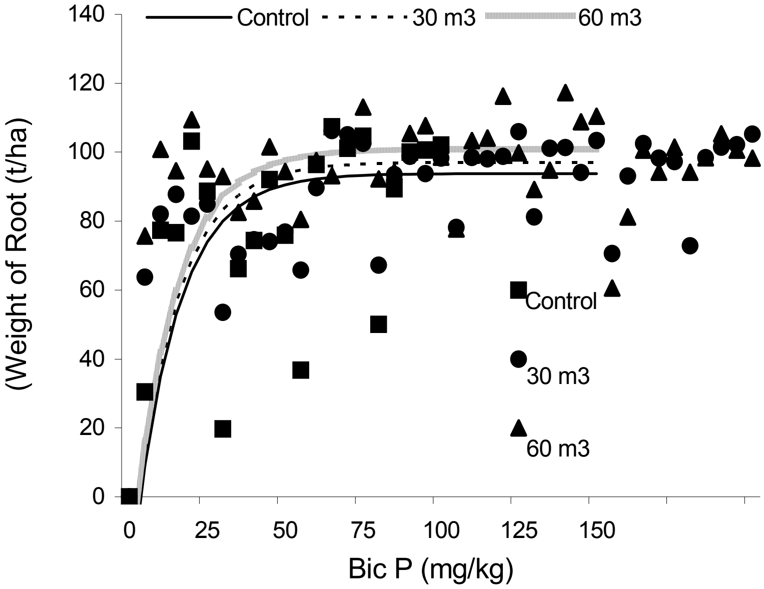


Figure 1.18. Response of total weight of carrot to soil content of Bic P at seeding and Compost rate.

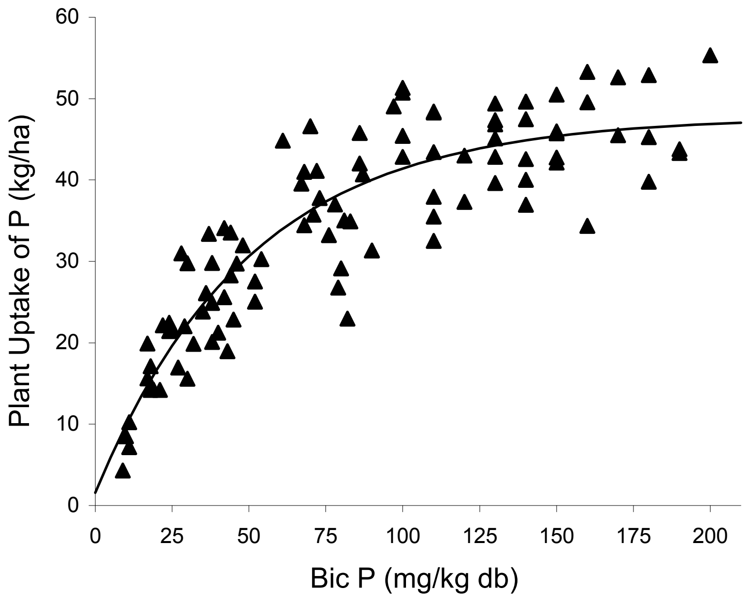


Figure 1.19. Relationship of P absorbed by plant and Bic P at seeding.

The relationship of total weight of Phosphorus taken up by the plant and soil content of Bic P at seeding was described by the function:

Plant uptake of Phosphorus = 47.75 – 46.18 $(0.98035)^{\wedge Phopshorus}$

The relationship accounted for 80 per cent of the observed variance and was consistent for Control and Compost treated plots and could not be grouped for rate or type of Compost (Figure 1.19).

The finding shows that the Bic P can be used to estimate plant available P in compost treated soils and soil Bic P requirements for crop production established on untreated soil are applicable to Compost amended soil.

The small yield increase seen in Compost treated soil (Figure 1.18) at the same level of Bic P suggests that something associated to Compost, other than P, was increasing plant production.

Reduction of plant available phosphorus

The reduction of Bic P in the top 15 cm of soil from sowing to harvest average 38 per cent and increased with increased rate of applied Phopshorus (Table 1.149). The reduction at the lower levels of applied Phosphorus was associated with a higher level of error at low concentrations and poorer growth exploiting a smaller soil volume.

Table 1.149. Percentage reduction of Bic P between sowing and harvest

Treatment	***Phosphorus application kg/ha***				
	0	***50***	***125***	***200***	***275***
Reduction %	*24.4*	*35.1*	*40.1*	*43.2*	*46.7*

Growing conditions

Typical winter growing conditions were experienced and irrigation management met recommendations (Figure 1.20).

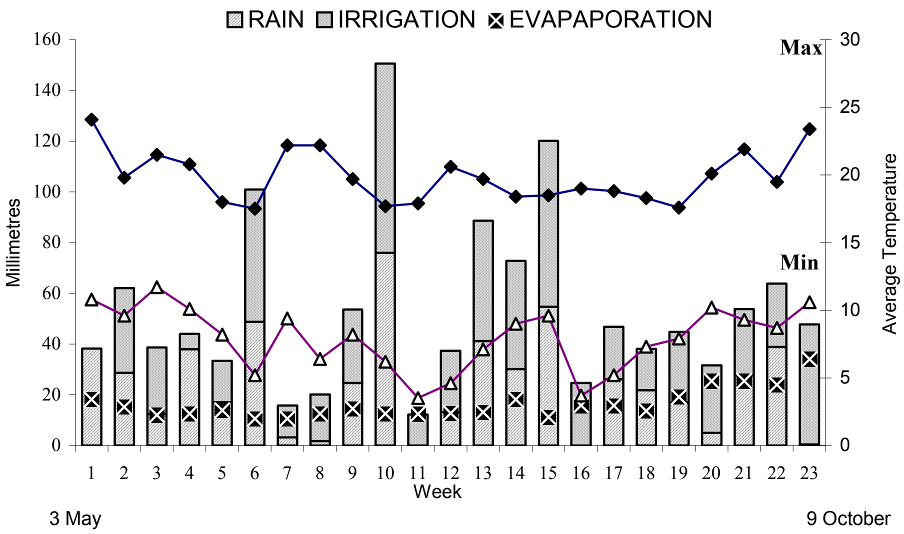


Figure 1.20. Weather conditions Carrot Crop 1.

Leaching

Three replications of all main plots receiving no applied Phosphorus were measured. All main plots leached a similar amount of water with 75 per cent or 930 mm of the 565 mm of rain plus 675 mm of irrigation being collected in the drainage lysimeters. Evaporation was 374 mm and the apparent crop water use (rain + irrigation - drainage) was 310 mm or 83 per cent of evaporation.

Leachate analysis over the first 10 weeks showed no soluble reactive Phosphorus (< 0.001 mg/kg) but small and similar quantities (average of 116 gm/ha) of Total Phosphorus were leached from all main plots receiving no applied Phosphorus.

Discussion

Results show that 100 kg of Phosphorus in Compost is equivalent to 40 kg of Phosphorus contained in Super Phosphate. Bicarbonate Phosphorus content determined for Compost amended soil was equivalent to that determined for unamended soils and gave similar concentrations in harvested plants.

Despite its poor quality Compost A produced more Top than Control or Compost B treated plots (Table 1.136) and the higher phosphorus content of Compost B caused it to produce more carrots at lower levels of applied Phosphorus (Figure 1.17 and Table 1.137).

Lettuce – Crop 2

The following fertiliser and compost treatments were applied and incorporated into the soil one week prior to Lettuce, variety *raider*, on 6 December 2001.

Treatment	Compost rates m^3/ha	Phosphorus rate kg N/ha	
Control	Nil	P1	Nil
A1/B1	30	P2	25
A2/B2	60	P3	75
		P4	125
		P5	175

In addition all plots received a total of 450 kg of Nitrogen, 500 kg of Potassium, 25 kg of Magnesium applied through the sprinkler system throughout the trial. Week 1-2, 10 per cent; week 2-3, 20 per cent; week 3-4, 30 per cent; week 4-5, 30 per cent; week 5-6, 10 per cent of the total applied. The lettuce were harvested at 40 days on 14 January 2002. An intermediate harvest weight was recorded at 21 days on 27 December 2001.

Compost quality

Compost A had a C/N ratio of 19, low toxicity but contained no plant available nitrogen. Compost B was a coarse woody batch originally used for the carrot – crop 2 in the Nitrogen site and had been matured further. While its C/N ratio had improved from 31 to 25 it still failed to meet the required standards (Appendix 1.1 Compost 3A and 2B).

Compost	Carbon Nitrogen Ratio	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 1A	19	0.30	86	1.7	< 1.0	< 0.1
Compost B	25	0.29	90	1.3	< 1.0	< 0.1

Harvest 21 days

Fresh weight

Within the main plot stratum production was affected by both compost type and rate (P = 0.032 and 0.043; Tables 1.150, 1.151).

Table 1.150. Total weight of lettuce at 21 days (t/ha)

Treatment	Lettuce
Control	6.35a*
Compost A	7.44b
Compost B	6.98c

* Values followed by a different subscript are different (P < 0.05).

Table 1.151. Total weight of lettuce at 21 days (t/ha)

Treatment	Lettuce
Control	6.35a*
Compost 30 m^3	6.99b
Compost 60 m^3	7.42c

* Values followed by a different subscript are different (P < 0.05).

There was an interaction between applied Phosphorus and Compost type (P = 0.001) and the quadratic response of plant weight to applied Phosphorus was different for each type of Compost (P = 0.01; Table 1.152).

Table 1.152. Total plant weight of lettuce at 21 days (t/ha)

Treatment	*Phosphorus application kg/ha*				
	0	***25***	***755***	***125***	***175***
Control	*1.16*	*4.16*	*7.33*	*9.38*	*9.70*
Compost A	*2.98*	*6.64*	*8.30*	*10.06*	*9.22*
Compost B	*3.69*	*5.32*	*8.18*	*8.37*	*9.31*

lsd 5%		
	Control vs Composts	1.07
	Compost A v B	0.88
	Controls between Phosphorus	1.25
	Compost between Phosphorus	0.89

Compost A and B produced more growth at the lower rates of applied Phosphorus and there was a trend for Compost B to produce less at higher rates of applied Phosphorus. This was consistent with compost supplying Phosphorus and the poor quality of Compost B potentially reducing production.

The linear response of total plant weight to applied Phosphorus was different for rate of Compost applied and while Compost increased production at the lower rate of applied Phosphorus the trend was for it to reduce production at higher rates of applied Phosphorus (P = 0.017; Table 1.153).

Table 1.153. Total plant weight of lettuce at 21 days (t/ha)

Treatment	*Phosphorus application kg/ha*				
	0	***25***	***755***	***125***	***175***
Control	*1.16*	*4.16*	*7.33*	*9.38*	*9.70*
Compost 30 m^3	*2.56*	*5.90*	*8.00*	*9.02*	*9.47*
Compost 60 m^3	*4.10*	*6.06*	*8.48*	*9.41*	*9.06*

lsd 5%		
	Control vs Composts	1.07
	Compost A v B	0.88
	Controls between Phosphorus	1.25
	Compost between Phosphorus	0.89

Plant analysis at 21 days

Nitrogen content of whole plant

Nitrogen content increased with rate of applied Phosphorus and there was an interaction between rate of compost and applied Phosphorus (P = 0.003). The quadratic response of plant Nitrogen content to applied Phosphorus was different for each rate of Compost (P = 0.002; Table 1.154). This table implies that 60 m^3 of compost reduced plant content of Nitrogen at higher levels of applied Phosphorus. While the exponential regression of plant Nitrogen content against level of soil Bicarbonate Phosphorus at planting was significant (P < 0.001) it could not be grouped for Compost rate or type and accounted for only 40 per cent of the observed variance.

Table 1.154. Nitrogen content of lettuce at 21 days (% db)

Treatment	*Phosphorus application kg/ha*				
	0	***25***	***75***	***125***	***175***
Control	*3.90*	*4.56*	*4.97*	*4.85*	*5.06*
Compost 30 m^3	*4.27*	*4.92*	*4.92*	*5.04*	*4.82*
Compost 60 m^3	*4.64*	*4.88*	*4.85*	*4.66*	*4.88*

lsd 5%		
	Control vs Composts	0.37
	Compost 30 v 60	0.31
	Controls between Phosphorus	0.36
	Compost between Phosphorus	0.26

Phosphorus content of whole plant

Plant Phosphorus content increased with applied Phosphorus and there was an interaction between Compost rate and applied Compost. The linear response of plant Phosphorus content to applied Phosphorus was different for each rate of Compost (P = 0.021; Table 1.155).

Table 1.155. Phopshorus content of lettuce at 21 days (% db)

Treatment	Phosphorus application kg/ha				
	0	25	75	125	175
Control	0.14	0.34	0.46	0.58	0.64
Compost 30 m^3	0.24	0.40	0.51	0.62	0.61
Compost 60 m^3	0.31	0.42	0.54	0.57	0.62
lsd 5%	Control vs Composts		0.063		
	Compost 30 v 60		0.051		
	Controls between Phosphorus		0.064		
	Compost between Phosphorus		0.045		

Potassium content of whole plant

Potassium content was high and reflected the 500 kg/ha of Potassium fertiliser applied. There was an interaction between control, Compost treated plots and applied Phosphorus (P < 0.001) and the quadratic response of Control and treated plots to applied Phosphorus was different (P = < 0.001; Table 156).

Table 1.156. Potassium content of lettuce at 21 days (% db)

Treatment	Phosphorus application kg/ha				
	0	25	75	125	175
Control	5.05	6.19	6.77	6.51	6.48
Compost	6.36	6.74	6.77	6.66	6.83
lsd 5%	Control vs Compost		0.43		
	Controls between Phosphorus		0.49		
	Compost between Phosphorus		0.25		

Soil analysis at planting

Plant available phosphorus at planting

While there were significant differences between treatments within the main plot stratum and the linear relationship of Control and Compost treated plots to applied Phosphorus was different (P = 0.045) variation and analytical error meant that individual treatments could not be verified statistically (Table 1.157).

Table 1.157. Bicarbonate P Content of soil at seeding (mg/kg db)

Treatment	*Phosphorus application kg/ha*				
	0	**25**	**75**	**125**	**175**
Control	*9.5*	*31.8*	*63.8*	*118.3*	*170.0*
Compost A 30 m^3	*24.5*	*43.5*	*70.5*	*105.0*	*137.5*
Compost A 60 m^3	*36.2*	*58.2*	*85.0*	*110.3*	*190.0*
Compost B 30 m^3	*22.0*	*47.2*	*110.0*	*99.3*	*140.0*
Compost B 60 m^3	*36.2*	*59.0*	*91.0*	*130.0*	*167.5*

Relationships of plant available bicarbonate phosphorus

Total weight of plant produced

The relationship of soil Bicarbonate Phosphorus at planting and total plant weight at 21 days was described by exponential curves fitted to the plot data and grouped for compost type (P = 0.031; Figure 1.21). The relationships accounted for 81 per cent of the observed variance and were described by the functions:

Control = 10.07 – 11.81 (0.97572)^Phosphorus
Compost A = 9.90 – 11.81 (0.97572)^Phosphorus
Compost B = 9.31 – 11.81 (0.97572)^Phosphorus

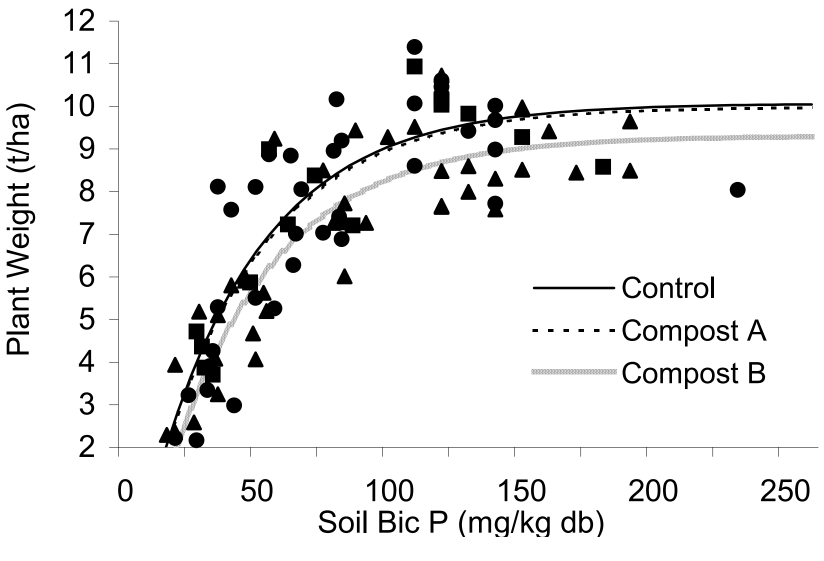


Figure 1.21. Relationship of total plant weight at 21 days and Soil Bic P at planting. ■ Control; ● Compost A; ▲ Compost B.

Compost B produced lower plant weight relative to soil Bicarbonate Phosphorus content than Control and Compost A treated plots. This was consistent with production data shown in Tables 1.149 and confirmed the reduced growth recorded for Compost B was caused by a factor other than lower plant available Phosphorus.

Plant phosphorus content

The exponential relationship of soil Bicarbonate Phosphorus and Phosphorus content of plant accounted for 86.1 per cent of the observed variance and could not be grouped for Compost type or rate ($P < 0.001$; Figure 1.22). The relationship was described by the function:

$\% \text{ P Content} = 0.6397 - 0.6345\ (0.97906)^{\text{Soil Bic P}}$

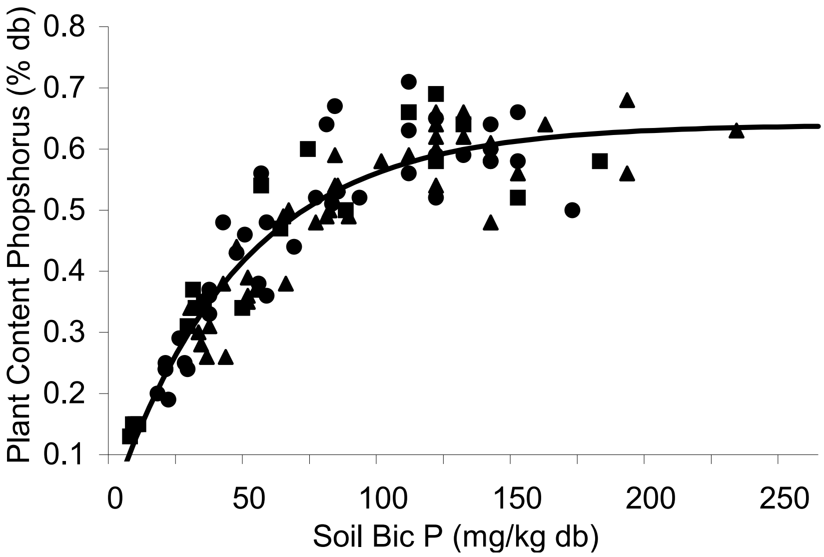


Figure 1.22. Response of plant phosphorus to soil bicarbonate phosphorus content at planting.

■ Control; ● Compost 30 m³; ▲ Compost 60 m³.

Final harvest 40 days

Fresh weight

Within the main plot stratum the weight of lettuce harvested increased with rate of Compost ($P = 0.013$; Table 1.158).

Table 1.158. Total weight of lettuce at 40 days (t/ha)

Treatment	Lettuce
Control	53.65a*
Compost 30 m³	61.68b
Compost 60 m³	65.49c

* Values followed by a different subscript are different ($P < 0.05$).

The quadratic response of total weight of lettuce harvested to applied Phosphorus was different for different rates of Compost ($P = 0.013$; Table 1.159) and there was an interaction between applied Phosphorus and Compost rate ($P < 0.001$). Compost was supplying plant available Phosphorus and yield increased at the lower rates of applied Phosphorus.

Table 1.159. Total weight of Lettuce at 40 days (t/ha)

Treatment	*Phosphorus application kg/ha*				
	0	*25*	*75*	*125*	*175*
Control	*5.56*	*42.53*	*71.23*	*72.56*	*76.38*
Compost 30 m³	*27.55*	*59.82*	*72.23*	*73.51*	*75.31*
Compost 60 m³	*40.75*	*59.30*	*73.97*	*77.27*	*76.13*

lsd 5%	Control vs Composts	5.54
	Compost 30 v 60	4.52
	Controls between Phosphorus	5.83
	Compost between Phosphorus	4.12

An exponential curve fitted to the plot data for Total Plant Weight accounted for 90.9 per cent of the variance ($P < 0.001$; Figure 1.23).

The rate of applied Phosphorus to achieve 99% of maximum yield was 129.3 kg/ha for the control, 117.25 kg/ha for 30 m^3 of compost and 109.9 kg/ha for 60 m^3. This smaller difference is a reflection of the soil content of bicarbonate extractable Phosphorus in the majority of plots approaching levels at which lettuce where no longer responsive to applied Phosphorus (McPharlin *et al*. 1996).

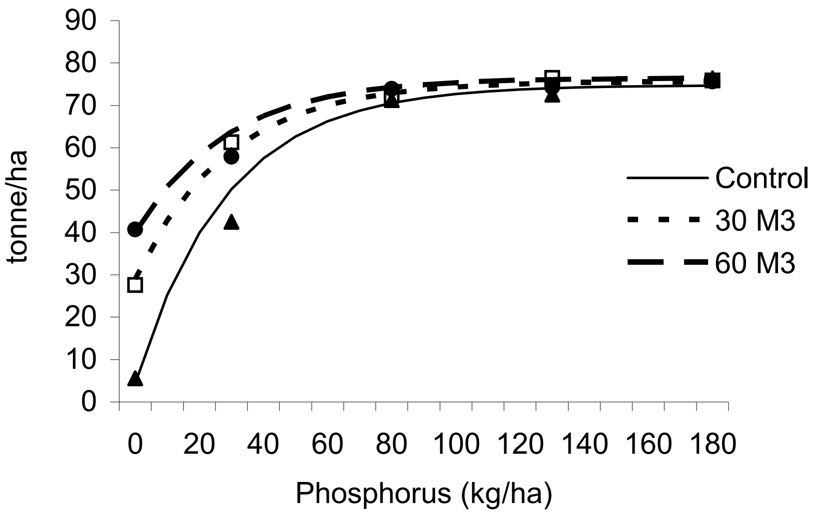


Figure 1.23. Response of total plant weight to applied phosphorus and rate of compost.

Weight of processed head

With the exception of the 2 lowest rates of applied Phosphorus the percentage head recovered was similar within rates of applied Phosphorus and relationships between treatments established for Total Weight were maintained for Weight of Processed Head (Table 1.160).

Table 1.160. Weight of processed head at 40 days (t/ha)

Treatment	Phosphorus application kg/ha				
	0	25	75	125	175
Control	0.0	20.24	36.44	39.36	40.64
Compost 30 m^3	10.62	31.43	38.91	39.73	39.62
Compost 60 m^3	17.68	30.31	39.14	40.42	40.58

lsd 5%	Control vs Composts	4.05
	Compost 30 v 60	3.30
	Controls between Phosphorus	4.40
	Compost between Phosphorus	3.11

Nitrogen content of whole plant

Nitrogen content was similar for all treatments and the trend for 60 m^3 of Compost to reduce Nitrogen levels was no longer evident (Table 1.161).

Table 1.161. Nitrogen content of whole lettuce at 40 days (% db)

Treatment	Phosphorus application kg/ha				
	0	25	75	125	175
Control	4.03	4.34	4.44	4.34	4.35
Compost 30 m^3	4.42	4.36	4.38	4.24	4.48
Compost 60 m^3	4.42	4.53	4.47	4.31	4..41

Phosphorus content of whole plant

The linear response of plant Phosphorus content with applied Phosphorus was different for each rate of Compost (P = 0.018; Table 1.162) and there was an interaction between applied Phosphorus and Compost rate (P = 0.026). This was a reflection of the Phosphorus being supplied by Compost.

Table 1.162. Phosphorus content of whole lettuce at 40 days (% db)

Treatment	Phosphorus application kg/ha				
	0	25	75	125	175
Control	0.220	0.365	0.548	0.668	0.668
Compost 30 m^3	0.416	0.471	0.549	0.664	0.716
Compost 60 m^3	0.448	0.506	0.620	0.649	0.688

lsd 5%	Control vs Composts	0.073
	Compost 30 v 60	0.059
	Controls between Phosphorus	0.066
	Compost between Phosphorus	0.047

Potassium content of whole plant

While the high level of Potassium fertiliser used removed major treatment differences expected from the Potassium supplied by Compost the quadratic response of plant Potassium content to applied Potassium was different for Control and the average of Compost treated plots (P = 0.049; Table 1.163).

Table 1.163. Potassium content of whole lettuce at 40 days (% db)

Treatment	Nitrogen application kg/ha				
	0	180	290	405	515
Control	5.62	6.07	6.32	6.14	5.78
Compost	6.58	6.66	6.68	6.23	6.34
lsd 5% Control vs Compost			ns		
lsd 5% Control between N levels			0.61		
lsd 5% Compost between N levels			0.31		

The higher plant weight (Table 1.159) and higher concentrations of Nitrogen Phosphorus and Potassium in Compost treated plots (Tables 1.161–1.163) meant higher plant uptake of these minerals were recorded for compost treated plots.

Soil analysis at harvest

Plant uptake reduced soil content of Bicarbonate Phosphorus and while within the main plot stratum there were differences between main plots (P = 0.045; Table 1.164) experimental and analytical error and natural variation meant no treatment differences beyond this were recorded.

Table 1.164. Soil content of Bic P at harvest (% db)

Treatment	Compost		
	Nil	30 m^3	60 m^3
Control	43.8a*		
Compost A		62.7bc	65.7cd
Compost B		55.7b	72.8d

* Values followed by a common subscript are not different (P > 0.05).

The relationship of Soil Bicarbonate Phosphorus at planting and Total Plant Weight at harvest was described by an exponential curve (P < 0.001; Figure 1.24) which accounted for 87.5 per cent of the observed variance. Data could not be grouped for Compost rate or type and the growth depression seen in Compost treated plots at 21 days had disappeared. The Total Weight of Plants harvested at 40 days was described by the function:

Plant Weight = 79.96 – 104.69* (0.96507)^$^{\text{Soil Bic P}}$

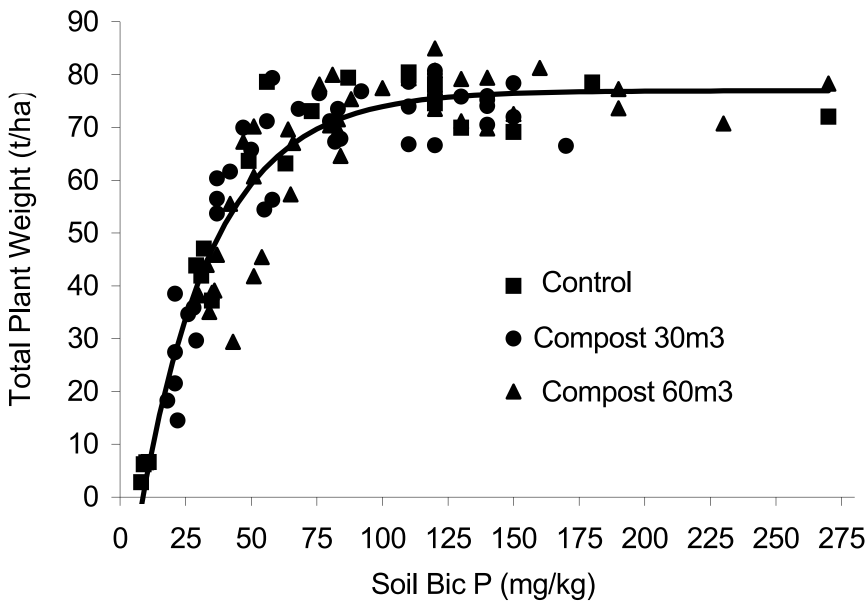


Figure 1.24. The relationship of total weight of lettuce harvested at 40 days and Soil Bicarbonate P at harvest.

Analysis of youngest fully mature wrapper leaf at harvest

YFML analysis is given in Table 1.165. While Copper levels were low, they were consistent with levels recorded on adjacent sites and were not considered critically deficient. Compost reduced Manganese.

Table 1.165. Analysis of lettuce wrapper leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range*
% db				
Phosphorus	0.44	0.49	0.04	0.55–0.65
Potassium	6.2	6.9	0.25	5.5–6.0
Sodium				0.5–1.0
Calcium	1.08	1.14	ns	1.4–2.0
Magnesium	0.30	0.29	ns	0.3–0.7
Sulphur	0.29	0.28	ns	0.3–0.32
mg/kg				
Boron	28	27	ns	25–55
Copper	6.7	6.1	ns	10–18
Iron	1212	1196	ns	50–500
Manganese	90	55	11	50–300
Zinc	60	44	8	30–100

* Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.
** Some samples exceeded 3.0 per cent the limit of analysis.

Growing conditions

Ideal summer growth conditions were experienced and irrigation met recommendations (Figure 1.25).

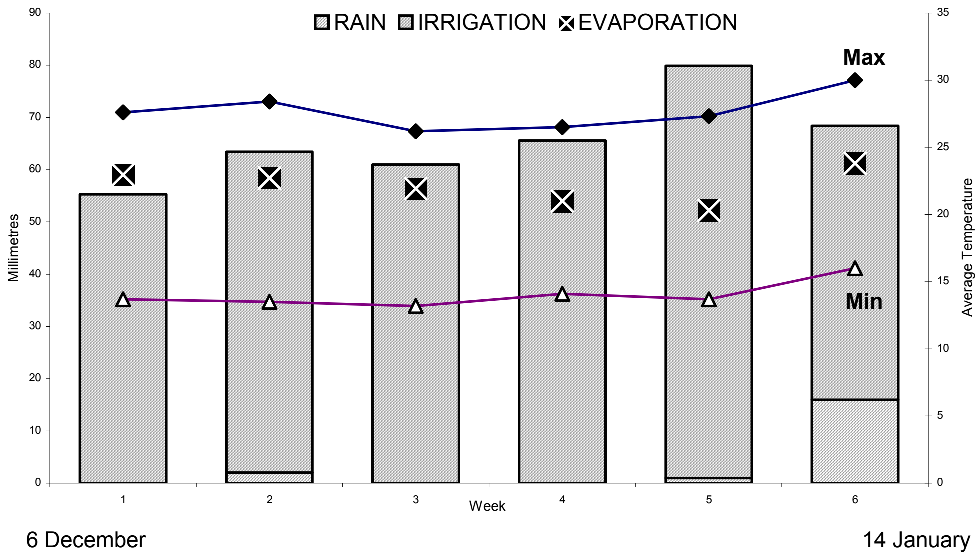


Figure 1.25. Weather conditions lettuce Crop 2.

Leaching

All plots measured leached a similar amount of water and 177 mm (44.9%) of the 375 mm of irrigation and 19 mm of rain was caught in the lysimeters. Apparent crop use, irrigation plus rain minus leaching, was 217 mm or 64 per cent of evaporation.

No soluble reactive Phosphorus (< 0.01 mg/L) was recorded and only a few of the samples contained detectable levels of total Phosphorus (> 0.1 mg/L).

Discussion

Phosphorus in Compost amended soil measured as Bicarbonate extractable Phosphorus was available for plant growth and gave equivalent plant growth to Bic P measured in Super Phosphate amended soil.

The growth depression seen at 21 days was attributed to the quality of the Compost applied competing for nitrogen in the early stages of growth. This effect had disappeared by harvest and Compost had no effect on growth independent of the supply of plant available Phosphorus.

Carrots - Crop 3

The compost treatments were applied and incorporated into the soil one week prior to seeding Carrots, variety *Stefano*, on 15 February 2002. No additional Phosphorus was applied and sub plot treatments were based on the residual from the previous 2 inorganic P applications.

Treatment	Compost rates m^3/ha	Phosphorus rate kg N/ha	
Control	Nil	P1	Nil
A1/B1	30	P2	Nil
A2/B2	60	P3	Nil
		P4	Nil
		P5	Nil

In addition all plots received a total of 340 kg of Nitrogen, 306 kg of Potassium, 15 kg of Magnesium and 1.5 kg Boron applied each week through the sprinkler system as a percentage of the total applied proportional to growth. The carrots were harvested at 143 days on 25 June 2002. An intermediate harvest weight was recorded at 62 days on 18 April 2002.

Compost quality

Compost A contained a low level of plant available Nitrogen (89 mg/L as nitrate), the Nitrogen Draw Down index (0.44) and Toxicity (100) indicated it was relatively stable and the C/N ratio was less than 20. Compost B, which had been compost A for Carrot – crop 2 in the Nitrogen site, had composted further and its analysis had improved in respect to the criteria we had established (Appendix 1.11 Compost 4A and 2B(2)).

Compost	Carbon Nitrogen Ratio	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 1A	19	0.44	100	1.6	89	> 1.0
Compost B	21	0.54	81	1.6	< 1.0	< 0.1

Harvest at 62 days

Plant density

There was no difference between treatments for plant density and all plots averaged 61 plant per square metre.

Carrot roots

Within the main plot stratum weight of carrot root increased with rate of applied Compost ($P = 0.039$; Table 1.166).

Table 1.166. Total weight of carrot root at 62 days (t/ha)

Treatment	Carrot
Control	5.33a*
Compost 30 m^3	6.95b
Compost 60 m^3	8.05c

* Values followed by a different subscript are different ($P < 0.05$).

There was a interaction between Compost treatment and previously applied Phosphorus and the linear response of Control and Compost treated plots was different (P < 0.001; Table 1.167).

Table 1.167. Weight of carrot root at 62 days (t/ha)

Treatment	Previously applied phosphorus kg/ha				
	0	75	200	325	450
Control	*0.52*	*3.42*	*7.92*	*7.53*	*7.24*
Compost	*5.72*	*7.12*	*7.84*	*8.66*	*8.15*

lsd 5%	Control vs Compost	1.97
lsd 5%	Control between P levels	2.35
lsd 5%	Compost between P levels	1.17

Weight of carrot top

There was a interaction between Compost treatment and previously applied Phosphorus and the linear response of Weight of Top was different for Control and Compost treated plots (P < 0.001; Table 1.168).

Table 1.168. Weight of top at 62 days (t/ha)

Treatment	Previously applied phosphorus kg/ha				
	0	75	200	325	450
Control	*0.91*	*3.80*	*6.33*	*6.77*	*6.30*
Compost	*5.76*	*6.57*	*7.04*	*7.57*	*7.18*

lsd 5%	Control vs Compost	1.54
lsd 5%	Control between P levels	1.65
lsd 5%	Compost between P levels	0.82

Soil bicarbonate phosphorus at planting

Soil analysis at planting for Bicarbonate extractable Phosphorus was variable and treatments could not be statistically verified beyond the main stratum effect of rate of Compost applied (P < 0.001) and a different linear relationship for Control and Compost treated plots and previously applied Phosphorus (P = 0.061). Treatment averages are given in Table 1.169.

Table 1.169. Bicarbonate P content of soil at seeding (mg/kg db)

Treatment	Previous applied phosphorus kg/ha				
	0	75	200	325	450
Control	*9.5*	*21.0*	*39.2*	*57.2*	*74.0*
Compost A 30 m^3	*35.0*	*45.2*	*69.2*	*94.5*	*105.2*
Compost A 60 m^3	*49.2*	*67.0*	*92.2*	*110.2*	*125.0*
Compost B 30 m^3	*29.5*	*43.0*	*61.8*	*84.2*	*105.0*
Compost B 60 m^3	*50.2*	*60.0*	*86.2*	*109.5*	*125.0*

Relationship of soil BIC P and total plant weight at 62 days

The relationship of the plot data for Total Plant Weight to soil Bic P at planting was described by an exponential curve with the function; Total Plant Weight = 16.28 – 19.81*(0.96325)^$^{Bic\ P}$ ($P < 0.001$) that accounted for only 47 per cent of the variance. The data could not be grouped for Compost rate or type. Most plots had sufficient Phosphorus to achieve maximum growth and variation between plots was caused by other factors.

Harvest at 143 days

Total weight of roots

Within the main plot stratum there was a significant effect of compost ($P < 0.001$) and compost rate ($P = 0.003$) on total weight of carrot produced. There was an interaction between applied Phosphorus and Compost Treatment ($P < 0.001$) and the response of Total Root Weight to the total amount of previously applied Phosphorus was different for Control and Compost treated plots ($P < 0.001$; Table 1.170).

Table 1.170. Weight of carrot root at 143 days (t/ha)

Treatment	***Previously applied phosphorus kg/ha***				
	0	***75***	***200***	***325***	***450***
Control	*29.6*	*63.5*	*66.2*	*78.6*	*70.8*
Compost	*68.6*	*68.8*	*72.5*	*71.7*	*72.5*

lsd 5%	Control vs Compost	9.0
lsd 5%	Control between P levels	11.4
lsd 5%	Compost between P levels	5.7

Carrots marketable as Grade A, B

Compost reduced the number of forked carrots at higher rates of applied Phosphorus (Table 1.172) and the Compost treated plots showed a different quadratic response to applied Phosphorus for Market A,B carrots ($P = 0.001$; Table 1.171).

Table 1.171. Weight of Market A,B carrots at 143 days (t/ha)

Treatment	***Previously applied Phosphorus kg/ha***				
	0	***75***	***200***	***325***	***450***
Control	*17.6*	*54.1*	*50.7*	*57.5*	*45.9*
Compost	*56.9*	*57.3*	*56.8*	*55.8*	*55.7*

lsd 5%	Control vs Compost	13.0
lsd 5%	Control between P levels	15.8
lsd 5%	Compost between P levels	7.9

Table 1.172. % Forked roots at 143 days

Treatment	*Previously applied Phosphorus kg/ha*				
	0	***75***	***200***	***325***	***450***
Control	*1.54*	*1.96*	*3.88*	*11.49*	*19.24*
Compost	*6.03*	*5.21*	*8.06*	*9.31*	*9.90*

lsd 5%	Control vs Compost	8.8
lsd 5%	Control between P levels	9.0
lsd 5%	Compost between P levels	4.5

An exponential curve fitted to treatment means grouped for rate of applied Compost gave a probability of $P < 0.001$ and accounted for 96.2 per cent of the variance (Figure 1.26).

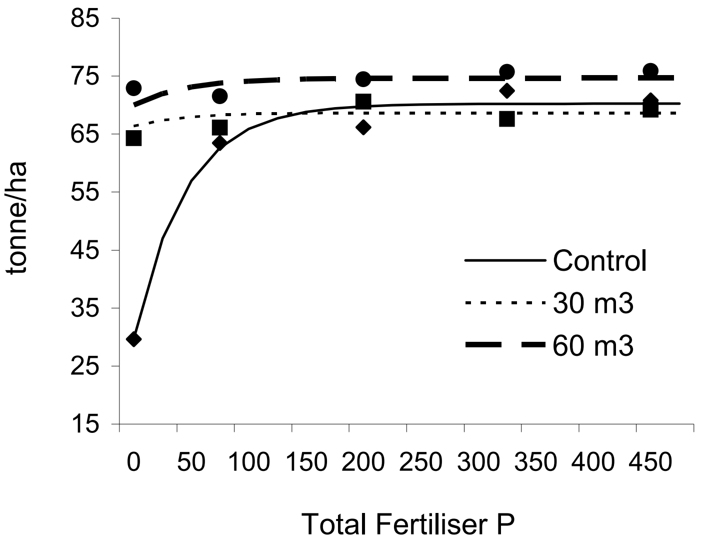


Figure 1.26. Response of carrot weight to applied Phosphorus and rate of compost.

The rate of previously applied Phosphorus that achieved 99 per cent of maximum yield was 181 kg/ha for the control, 53.3 kg/ha for 30 m^3 of compost and 82.0 kg/ha for 60 m^3.

An exponential curve fitted to treatment means of weight of carrots harvested and bicarbonate extractable P of soil at sowing for both carrot crops had a probability of $P < 0.001$ and accounted for 94.3 per cent of the variation (Figure 1.27).

Ninety nine per cent of maximum yield was achieved at a soil Bic P analysis of 66 mg/kg for the first carrot crop and 64 for the second. This is consistent with industry recommendations (McPharlin *et al.* 1997) and confirms that Bic P analysis of soil to which compost has been applied can be used to determine crop fertilise Phosphorus requirement (Figure 1.27).

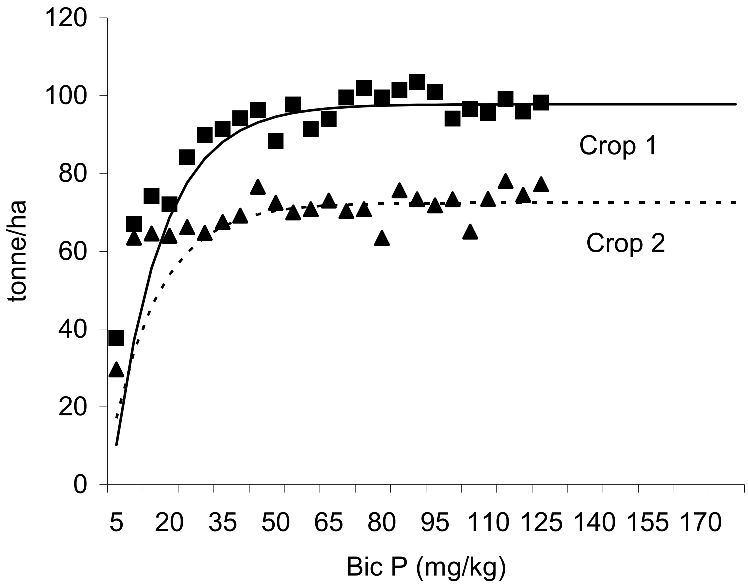


Figure 1.27. **Relationship of weight of carrot harvested and bicarbonate extractable Phosphorus at sowing.**

A linear relationship existed between soil Bic P, total applied fertiliser P and rate of applied compost (Figure 1.28). This relationship can be used to confirm that 100 kg of Phosphorus applied in compost increases soil Bic P by an amount equivalent to the application of 40 kg of inorganic P applied as single super phosphate.

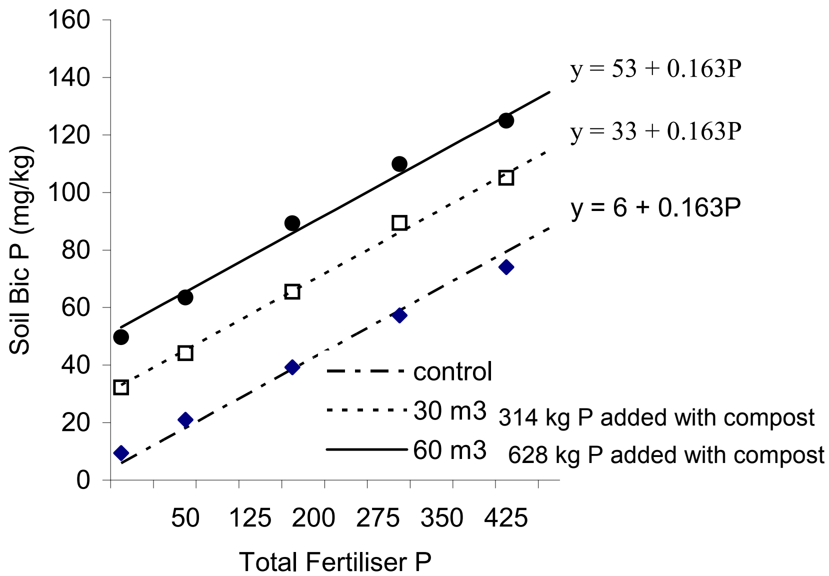


Figure 1.28. **Relationship of soil bicarbonate phosphorus, total applied phosphorus fertiliser and rate of compost applied.**

Weight of carrot top

Within the main plot stratum Top Weight increased with rate of Compost applied ($P < 0.001$; Table 1.173). There was an interaction between previously applied Phosphorus ($P < 0.001$) and Compost treatment and the linear and quadratic response of Top Weight to previously applied Phosphorus was different for Control and the average of the Compost treated plots ($P = 0.025$; Table 1.174).

Table 1.173. Weight of carrot top at 143 days (t/ha)

Treatment	Carrot
Control	14.4a*
Compost 30 m^3	16.8b
Compost 60 m^3	20.0c

* Values followed by a different subscript are different ($P < 0.05$).

Table 1.174. Weight of carrot top at 143 days (t/ha)

Treatment	*Previously applied Phosphorus kg/ha*				
	0	***75***	***200***	***325***	***450***
Control	*7.3*	*14.4*	*14.2*	*18.3*	*17.7*
Compost	*17.7*	*17.4*	*18.7*	*19.1*	*19.2*

lsd 5%	Control vs Compost	2.75
lsd 5%	Control between P levels	3.14
lsd 5%	Compost between P levels	2.48

The trend was for Compost to produce more Top Weight even at higher rates of applied Phosphorus.

Nitrogen phosphorus and potassium content at harvest

Leaf nitrogen

While there were no difference in the main plot stratum the linear response of Nitrogen content to previously applied Phosphorus was different ($P = 0.019$; Table 1.175) for Control and the average of Compost treated plots.

Table 1.175. Nitrogen content of leaf (% db)

Treatment	*Previously applied Phosphorus kg/ha*				
	0	***75***	***200***	***325***	***450***
Control	*2.70*	*2.33*	*2.26*	*2.29*	*2.25*
Compost	*2.35*	*2.32*	*2.32*	*2.34*	*2.37*

The trend was for plants from Compost treated plots to have higher levels of Nitrogen.

Root nitrogen

On average roots from Compost treated plots contained more Nitrogen (1.92%) than plants grown in Control Plots (1.72% db, $P = 0.004$). The linear response of root Nitrogen content for Control and the average of Compost treated plots was different ($P = 0.003$; Table 1.176).

Table 1.176. Nitrogen content of root (% db)

Treatment	***Previously applied Phosphorus kg/ha***				
	0	***75***	***200***	***325***	***450***
Control	*1.42*	*1.60*	*1.75*	*1.88*	*1.95*
Compost	*1.78*	*1.89*	*1.96*	*1.99*	*2.00*

Leaf phosphorus

On average Phosphorus content of carrots from Compost treated plots (0.225% db) was higher than Control (0.202%), ($P = 0.005$) and there was a linear response of leaf Phosphorus content to previously applied Phosphorus ($P < 0.001$; Table 1.177). No other differences were significant.

Table 1.177. Phosphorus content of shoot (% db)

Treatment	***Previously applied Phosphorus kg/ha***				
	0	***75***	***200***	***325***	***450***
Carrot Top	*0.21*	*0.20*	*0.21*	*0.23*	*0.25*

Root phosphorus

Within the main plot stratum Phosphorus content of root increased with rate of applied Compost ($P = 0.009$; Table 1.178).

Table 1.178. Phosphorus content of root at 143 days (% db)

Treatment	**Carrot**
Control	0.305a*
Compost 30 m^3	0.350b
Compost 60 m^3	0.381c

* Values followed by a different subscript are different ($P < 0.05$).

There was an interaction between previously applied Phosphorus and Compost treatment ($P < 0.001$) and the linear response of Phosphorus content of root to previously applied Phosphorus was different of Control and the average of the Compost treated plots ($P < 0.001$; Table 1.179).

Table 1.179. Phosphorus content of root at 143 days (% db)

Treatment	***Previously applied Phosphorus kg/ha***				
	0	***75***	***200***	***325***	***450***
Control	*0.202*	*0.252*	*0.290*	*0.368*	*0.412*
Compost	*0.313*	*0.326*	*0.365*	*0.396*	*0.429*

lsd 5%	Control vs Compost	0.036
lsd 5%	Control between P levels	0.040
lsd 5%	Compost between P levels	0.020

The higher Phosphorus content of leaf and root in plants grown in compost treated plots indicates a higher level of available Phosphorus in these plots.

Leaf potassium

The linear response of Potassium content of carrot leaf to previously applied Phosphorus was different for Control and Compost treated plots (P = 0.003; Table 1.180) and there was an interaction between applied Phosphorus and Compost treatment (P = 0.01).

Table 1.180. Potassium content of leaf at 143 days (% db)

Treatment	Previously applied Phosphorus kg/ha				
	0	75	200	325	450
Control	5.09	4.22	3.92	3.44	3.73
Compost	4.13	3.97	3.94	4.04	3.95
lsd 5% Control vs Compost			0.60		
lsd 5% Control between P levels			0.78		
lsd 5% Compost between P levels			0.39		

Root potassium

Similarly the linear response of Potassium content of carrot root to previously applied Phosphorus was different for Control and Compost treated plots (P < 0.001; Table 1.181) and there was an interaction between applied Phosphorus and Compost treatment (P < 0.001).

Table 1.181. Potassium content of root at 143 days (% db)

Treatment	Previously applied Phosphorus kg/ha				
	0	75	200	325	450
Control	3.03	2.77	2.68	2.50	2.42
Compost	2.80	2.87	2.90	2.83	2.83
lsd 5% Control vs Compost			0.20		
lsd 5% Control between P levels			0.25		
lsd 5% Compost between P levels			0.13		

The Potassium content of carrot leaf and shoot was increased by compost.

It is clear that the differences in N, P and K content were the result of better Phosphorus status of plots treated with compost and the better growth and nutrient status of plants grown in these plots would record higher uptakes.

Relationship to soil bicarbonate phosphorus

The relationship of soil Bicarbonate Phosphorus, Total Plant Weight and rate of applied Phosphorus was described by an exponential curve fitted to the plot data and grouped for rate of Compost applied. The site had become variable and the regression accounted for only 46.9 per cent of the observed variance but did suggest compost at the high rate of application increased growth beyond its effect on soil Bicarbonate Phosphorus (Figure 1.29). The total weight of plant produced was described by the functions:

Control = 87.43 – 445* (0.7931)^$^{Bic P}$
Compost 30 m^3 = 87.41 – 52* (0.9452)^$^{Bic P}$
Compost 60 m^3 = 90.63 + 0.05* (1.0414)^$^{Bic P}$

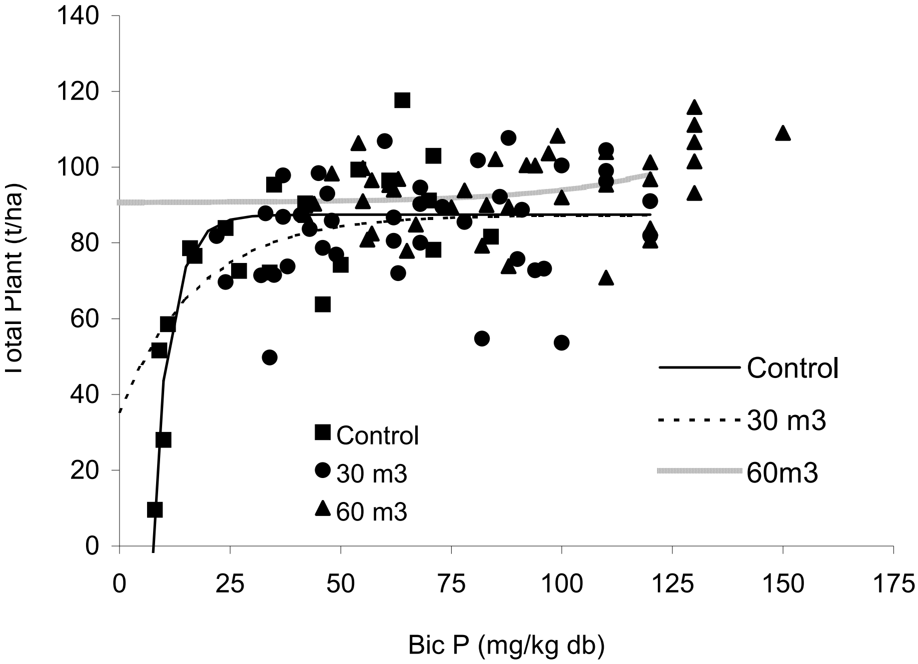


Figure 1.29. **Relationship of soil bicarbonate phosphorus, total plant weight and rate of applied compost.**

Analysis of youngest fully mature leaf at harvest

YFML analysis is given in Table 1.1182. Phosphorus content of treated plots was slightly higher. Compost reduced Manganese and Zinc concentrations.

Table 1.182. **Analysis of carrot YFML at harvest**

Analyt	Control	Compost	*5% lsd*	Normal range*
% db				
Phosphorus	0.23	0.26	0.01	0.3–0.4
Potassium	4.2	4.1	Ns	1.3–1.5
Sodium	1.57	1.62	Ns	0.7–4.5
Calcium	1.21	1.30	Ns	1.8–2
Magnesium	0.23	0.23	Ns	0.35–0.40
Sulphur	0.32	0.30	0.02	0.3–0.6
mg/kg				
Boron	33	31	1.1	29–35
Copper	5.3	4.0	Ns	5–7
Iron	319	361	Ns	120–350
Manganese	61	29	5	190–350
Zinc	27	20	2.0	20-50

* Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.

Growing conditions

Growing conditions were typical of late summer and irrigation was managed to meet recommendations (Figure 1.30).

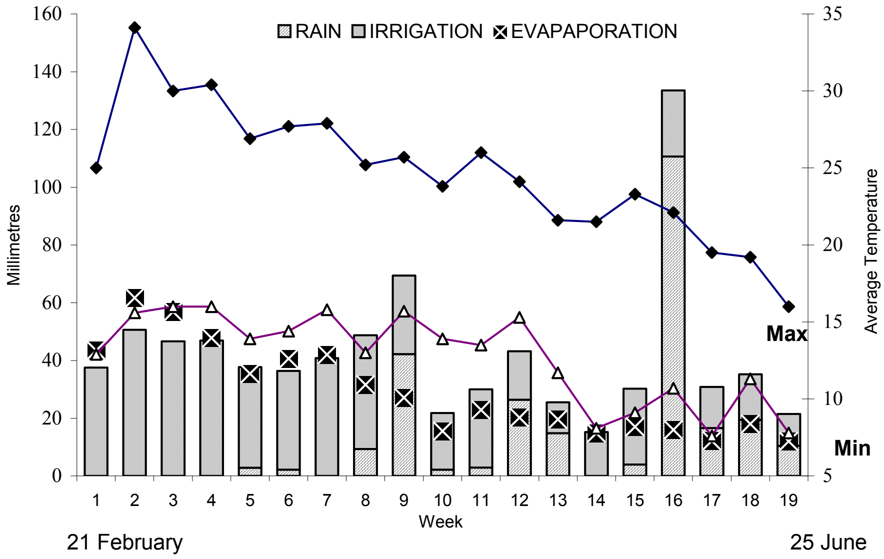


Figure 1.30. Crop conditions carrots crop 3.

Discussion

The trial confirmed that 100 kg of Total Phosphorus supplied by compost was equivalent to 40 kg of Phosphorus supplied by single superphosphate. Plots which had received the high rate of Compost showed increased growth beyond the additional growth explained by higher soil Bicarbonate Phosphate. The higher nitrogen content in these plots (Table 1.171 and 172) and better top growth (Table 1.170) indicate that the additional growth was caused by better nitrogen nutrition. Plots which had received high applications of inorganic Phosphorus recorded an increased incidence of forked carrots (Table 1.172).

Conclusions – phosphorus site

The standard bicarbonate soil test widely used in Western Australia to determine crop phosphorus requirements can be used in compost amended sandy soils of the Swan Coastal Plain (Figures 1.18, 1.21 and 1.27).

The trials have also indicated that from the initial compost application, 40% of the phosphorus contained in compost can replace an equivalent amount of inorganic phosphorus supplied as single superphosphate (Figure 1.28). Therefore with continued use of compost, plant requirements based on standard soil testing procedures will account for changing total soil phosphorus status and reliably predict additional crop requirements.

Results – potassium replacement trial site

Lettuce - Crop 1

The following compost treatments were applied and incorporated into the soil together with an application of 360 kg per hectare of Phosphorus and trace minerals one week prior to transplanting lettuce, variety *magnum*, on 20 September 2001.

Treatment	Compost rates m^3/ha	Potassium rate kg N/ha	
Control	Nil	K1	Nil
A1	30	K2	150
A2	60	K3	250
B1	30	K4	350
B2	60	K5	450

The potassium was applied as the nitrate weekly by watering can together with a total of 450 kg/ha of nitrogen. Week 1, 8 per cent; week 2, 17 per cent; week 3, 17 per cent; week 4, 16 per cent; week 5, 16 per cent; week 6, 14 per cent and week 7, 12 per cent of the total applied. The lettuce was harvested at 56 days on 15 November. Intermediate growth was recorded on 12 October at 22 days.

Compost quality

The fresh compost supplied was coarse and woody and met few of the criteria considered necessary to record a positive crop response. The chemical analysis of compost B had changed very little during the 12 week period it had been kept moist and turned twice (Appendix 1.1, Compost 2A and B1).

Compost	Carbon Nitrogen Ratio	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 1A	31	0.34	98	1.3	23	> 1.0
Compost B	28	0.26	95	1.4	< 1.0	< 0.1

Harvest at 22 Days

Fresh weight

Within the main plot stratum plots treated with compost recorded higher fresh (4.0 tonne/ha) weight than Control plots (3.7 tonne). The linear response of fresh weight to applied Potassium was different for Compost Type (P = 0.039; Table 1.178).

Table 1.178. Fresh weight of lettuce at 22 days (tonne/ha)

Treatment	*Potassium application kg/ha*				
	0	*38*	*62*	*90*	*112*
Control	*3.34*	*3.66*	*3.61*	*3.66*	*4.23*
Compost A	*3.92*	*4.11*	*4.07*	*4.26*	*3.89*
Compost B	*3.59*	*3.87*	*3.95*	*4.09*	*4.22*

lsd 5%	Control vs Composts	0.49
	Compost A v B	0.40
	Controls between K Levels	0.58
	Compost between K Levels	0.41

The trend was for Compost treated plots to record higher fresh weight at the lower rates of applied Potassium. This indicated Compost was supplying plant available Potassium.

Plant analysis

Nitrogen content

Within main plots plants from Compost A treated plots had lower Nitrogen content (P = 0.03; Table 1.179) than plants grown in Control and Compost B treated plots.

Table 1.179. Nitrogen content of Lettuce at 22 days (% db)

Treatment	Carrot
Control	5.819a*
Compost A	5.628b
Compost B	5.717a

* Values followed by a common subscript are not different (P > 0.05).

While the trend was for Nitrogen content to decrease with increasing level of applied Potassium (P < 0.001), the trend for plants from Compost A treated plots to record lower concentrations of Nitrogen than plants from Compost B and Control plots suggests Compost A reduced plant available Nitrogen (P = 0.063; Table 1.180).

Table 1.180. Nitrogen content of lettuce at 22 days (% db)

Treatment	*Potassium application kg/ha*				
	0	*38*	*62*	*90*	*112*
Control	*5.93*	*6.01*	*5.74*	*5.72*	*5.71*
Compost A	*5.82*	*5.58*	*5.57*	*5.65*	*5.51*
Compost B	*6.02*	*5.75*	*5.74*	*5.58*	*5.50*

lsd 5%	Control vs Composts	0.257
	Compost A v B	0.210
	Controls between K Levels	0.312
	Compost between K Levels	0.221

Phosphorus

Plant Phosphorus content averaged 0.618% db and there was no effect of treatment.

Potassium

Within the main plot stratum plant content of Potassium increased with rate of Compost applied (P = 0.002; Table 1.181).

Table 1.181. Potassium content of Lettuce at 22 days (% db)

Treatment	Lettuce
Control	4.363a*
Compost 30 m^3	5.195b
Compost 60 m^3	5.616c

* Values followed by a different subscript are different (P < 0.05).

There was an interaction between applied Potassium and Compost for plant content of Potassium (P = 0.013) and the linear response of plant Potassium content to applied Potassium was different for Control and Compost treated plots and Compost increased plant Potassium content. (P = 0.002; Table 1.181).

Table 1.181. Potassium content of Lettuce at 22 days (% db)

Treatment	*Applied Potassium kg/ha*				
	0	***38***	***62***	***90***	***112***
Control	*2.59*	*4.19*	*4.65*	*5.08*	*5.30*
Compost	*4.30*	*5.28*	*5.50*	*5.81*	*6.13*
lsd 5%	Control vs Compost		0.45		
	Control between K levels		0.54		
	Compost between K levels		0.27		

Harvest at 56 Days

Analysis of variance showed compost (P < 0.001) and compost rate (P < 0.003) increased the total weight of lettuce harvested and there was a significant interaction between Rate of Compost and applied Potassium (P < 0.001; Table 1.182). The response of Fresh Weight to applied Potassium was different for each rate of Compost (P < 0.001).

Table 1.182. Fresh weight of lettuce at 56 days (tonne/ha)

Treatment	*Potassium application kg/ha*				
	0	***150***	***250***	***350***	***450***
Control	*34.47*	*67.90*	*72.08*	*78.37*	*82.30*
Compost 30 m^3	*54.37*	*73.80*	*79.01*	*80.57*	*83.35*
Compost 60 m^3	*66.40*	*74.87*	*79.94*	*83.34*	*81.02*
lsd 5%	Control vs Composts		4.53		
	Compost 30 m^3 v 60 m^3		3.70		
	Controls between K Levels		5.34		
	Compost between K Levels		3.78		

An exponential curve fitted to the plot data and grouped for rate of applied Compost had a probability of < 0.001 and accounted for 88.3 per cent of the observed variance (Figure 1.31). The weight of fresh lettuce harvested was described by the functions:

Control = $83.63 - 48.80\ (0.9933)^{Potassium}$
30 m^3 = $84.40 - 29.91\ (0.9933)^{Potassium}$
60 m^3 = $82.88 - 16.93\ (0.9933)^{Potassium}$

The amount of applied Potassium required to achieve 95 per cent of the maximum yield was 368 kg/ha for the control, 293 kg for plots which had received 30 m^3 of compost (75 kg less) and 211 kg for 60 m^3 (157 kg less). It was calculated that on average 30 cubic metre of Compost applied approximately 63 kg of Potassium. The K in compost was therefore freely available and compost has a sparing effect on applied K of about 15–20 per cent, i.e. 100 kg of K applied, as compost is equivalent to 115 kg of K applied as fertiliser.

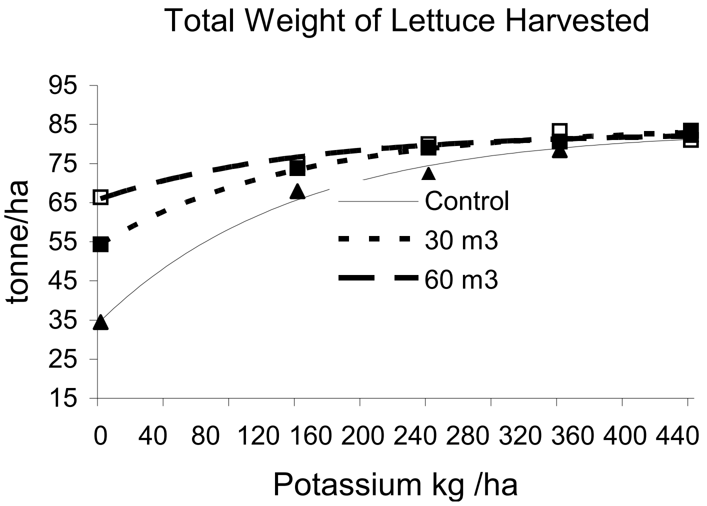


Figure 1.31. Lettuce harvested (t/ha) in response to applied potassium.

Marketable head

Plants were harvested a little beyond optimum heart density and 66.6 per cent of the total plant was recovered, as processed head. While percentage recovery increased with increasing application of applied Potassium there was no other treatment effect and relative differences between treatments shown in Figure 1.31 were maintained.

Plant analysis

Nitrogen

Plant nitrogen content average 3.6 per cent and there were no treatment effects.

Phosphorus

While Phosphorus content increased with application of Potassium there were no main plot effects (Table 1.183).

Table 1.183. Phosphorus content of lettuce at 56 days (% db)

	Potassium application kg/ha				
	0	150	250	350	450
All treatments	0.654	0.686	0.728	0.706	0.736

Potassium

Plant Potassium content increased with applied Potassium and Compost Rate, there was an interaction between Compost rate and applied Potassium and the linear response of plant concentration of Potassium to applied Potassium was different for each rate of Compost (P = 0.008; Table 1.184).

Table 1.184. Potassium content of lettuce at 56 days (% db)

Treatment	Potassium application kg/ha				
	0	150	250	350	450
Control	1.65	2.98	4.55	5.10	5.94
Compost 30 m^3	1.46	2.84	4.75	5.79	6.30
Compost 60 m^3	2.10	3.86	5.08	5.85	6.36

lsd 5%	Control vs Composts	0.62
	Compost 30 m^3 v 60 m^3	0.51
	Controls between K Levels	0.66
	Compost between K Levels	0.47

Plant uptake

Nitrogen

The better growth achieved by compost treated plots at low rates of applied Potassium resulted in an interaction between Compost and applied Potassium (P = 0.004) and the response of plant uptake of Nitrogen to applied Potassium was higher at low rates of applied Potassium (P = 0.001; Table 1.185).

Table 1.185. Nitrogen uptake by lettuce at 56 days (kg/ha)

Treatment	Potassium application kg/ha				
	0	150	250	350	450
Control	71.6	124.1	133.7	142.3	139.8
Compost 30 m^3	114.8	132.2	139.0	140.4	143.2

lsd 5%	Control vs Composts	19.0
	Controls between K Levels	22.1
	Compost between K Levels	11.1

Phosphorus

A similar response was demonstrated for uptake of Phosphorus (P = 0.006; Table 1.186).

Table 1.186. Phosphorus uptake by lettuce at 56 days (kg/ha)

Treatment	***Potassium application kg/ha***				
	0	***150***	***250***	***350***	***450***
Control	*13.0*	*24.0*	*27.2*	*26.6*	*27.5*
Compost 30 m³	*21.4*	*25.3*	*27.4*	*27.8*	*28.9*

lsd 5%	Control vs Composts	3.5
	Controls between K Levels	4.3
	Compost between K Levels	2.2

Potassium

Within the main plot stratum plant uptake of Potassium increased with Compost rate (P = 0.009; Table 1.187).

Table 1.187. Potassium uptake by lettuce at 56 days (kg/ha)

Treatment	**Lettuce**
Control	143.6a*
Compost 30 m³	159.4a
Compost 60 m³	179.6b

* Values followed by a common subscript are not different (P > 0.05).

The linear response of plant uptake of Potassium to applied Potassium was different for each rate of Compost (P = 0.031; Table 1.188).

Table 1.188. Potassium uptake by lettuce at 56 days (kg/ha)

Treatment	***Potassium application kg/ha***				
	0	***150***	***250***	***350***	***450***
Control	*33.1*	*100.0*	*161.6*	*195.2*	*228.1*
Compost 30 m³	*45.3*	*103.9*	*176.7*	*225.2*	*246.0*
Compost 60 m³	*71.9*	*146.3*	*201.7*	*232.0*	*245.8*

lsd 5%	Control vs Composts	30.6
	Compost 30 m³ v 60 m³	25.0
	Controls between K Levels	33.9
	Compost between K Levels	23.9

Analysis of youngest fully mature wrapper leaf at harvest

YFML analysis is given in Table 1.189. While Copper levels were low, they were consistent with levels recorded on adjacent sites and were not considered critically deficient. Compost reduced Manganese.

Table 1.189. Analysis of lettuce wrapper leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range*
% db				
Phosphorus	0.732	0.714	ns	0.55–0.65
Potassium	> 4.0	> 4.0		5.5–6.0
Sodium	1.08	0.94	0.07	0.5–1.0
Calcium	0.71	0.75	ns	1.4–2.0
Magnesium	0.229	0.309	ns	0.3–0.7
Sulphur	0.228	0.219	ns	0.3–0.32
Mg/kg				
Boron	30.00	29.0	1.0	25–55
Copper	3.67	4.5	ns	10–18
Iron	512	473	ns	50–500
Manganese	81	65	7.2	50–300
Zinc	49	51	ns	30–100

* Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.
** Most samples exceeded 4.0 per cent the limit of analysis.

Soil analysis at planting

Within the main plot stratum soil Bicarbonate extractable Potassium increased with Compost rate (P = 0.004; Table 1.190).

Table 1.190. Potassium content of soil at planting (mg/kg db)

Treatment	Carrot
Control	11.9a*
Compost 30 m^3	41.8b
Compost 60 m^3	59.3c

* Values followed by a different subscript are different (P < 0.05).

Average Bicarbonate extractable Potassium content of the 4 replicate plots of each treatment is given in table 1.191. While some treatments showed significant variation within main plots (5% LSD = 16.3) differences between main plots were relatively consistent (5% LSD = 20.4) with compost application increasing soil Potassium.

Table 1.191. Bicarbonate K content of soil at planting (mg/kg db)

Treatment	***Phosphorus application kg/ha***				
	0	***150***	***250***	***350***	***450***
Control	*12.0*	*13.0*	*11.7*	*11.7*	*11.2*
Compost A 30 m^3	*37.0*	*44.8*	*51.8*	*44.7*	*50.8*
Compost A 60 m^3	*75.2*	*73.0*	*45.7*	*70.5*	*79.0*
Compost B 30 m^3	*38.8*	*40.3*	*30.0*	*41.0*	*39.2*
Compost B 60 m^3	*62.5*	*50.2*	*50.5*	*43.0*	*43.0*

Soil analysis at harvest

Analysis of soil Bicarbonate Potassium at harvest showed that Potassium not absorbed by the plant was readily leached and while residual Potassium was still present at high rates of applied Potassium differences between the average of main plots were small (Tables 1.192 and 1.193).

Table 1.192. Potassium content of soil at harvest (mg/kg db)

Treatment	**Carrot**
Control	24.8a*
Compost 30 m^3	24.5a
Compost 60 m^3	27.8b

* Values followed by a similar subscript are not different (P > 0.05).

Table 1.193. Bicarbonate K content of soil at harvest (mg/kg db)

	Potassium application kg/ha				
	0	***150***	***250***	***350***	***450***
Treatments	*9.9a**	*17.8b*	*26.3c*	*34.9d*	*40.6e*

* Values followed by a similar subscript are not different (P > 0.05).

Growing conditions

Conditions were typical of spring and irrigation met recommendations.

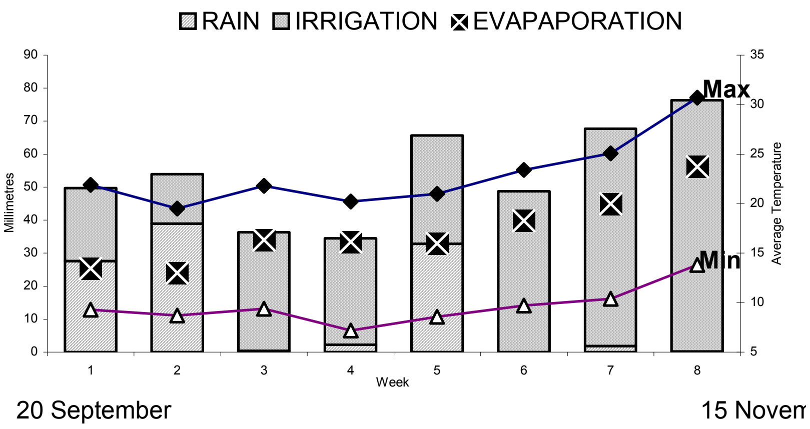


Figure 1.32 Growing conditions Crop 1 – Lettuce.

Discussion

Results showed that Potassium supplied by the application of Compost is freely available to plants and compost has a sparing effect on Potassium supplied as the nitrate. The concentration and plant uptake of Potassium increased with increased application of Potassium.

Despite the high rate of Nitrogen used the poor quality of Compost A lowered plant nitrogen concentration a 22 days (Tables 1.179 and 1.180). This was not evident at harvest.

Compost is a good source of Potassium and 100 kg of Potassium supplied by Compost will substitute for 115-120 kg of Potassium supplied as the nitrate.

Carrot – Crop 2

The following compost treatments were applied and incorporated into the soil together with an application of 200 kg per hectare of Phosphorus and trace minerals one week prior seeding carrots, variety *Stefano*, on 17 December 2001.

Treatment	Compost rates m^3/ha	Potassium rate kg N/ha	
Control	Nil	K1	Nil
A1	30	K2	50
A2	60	K3	75
B1	30	K4	125
B2	60	K5	225

The potassium was applied as the nitrate by watering can weekly as a percentage of the total applied in proportion to growth together with a total of 320 kg/ha of nitrogen, 22 kg/ha Magnesium and 1.5 kg/ha of Boron. The carrots were harvested at 114 days on 10 April 2002. Root and top growth was recorded on 15 February at 60 days.

Compost quality

Compost A had a C/N ratio of 19, low toxicity but contained no plant available nitrogen. Compost B was a coarse woody batch originally used for the carrot – crop 2 in the Nitrogen and had been matured further. While its C/N ratio had improved from 31 to 25 it still failed to meet the required standards (Appendix 1.11 Compost 3A and 2B). The compost used were the same batches as used for the second trial in the Phosphorus site (Lettuce).

Compost	Carbon Nitrogen Ratio	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 3A	19	0.30	86	1.7	< 1.0	< 0.1
Compost 2B	25	0.29	90	1.3	< 1.0	< 0.1

Results

Soil analysis at planting

The incorporation of crop residues and application of Compost dramatically increased Bicarbonate extractable Potassium concentration in the soil at planting. Within the main plot stratum soil Potassium increased with Compost Rate ($P < 0.001$; Table 1.194).

Table 1.194. Potassium content of soil at planting (mg/kg db)

Treatment	Carrot
Control	35.6a*
Compost 30 m^3	89.1b
Compost 60 m^3	133.3c

* Values followed by a different subscript are different ($P < 0.05$).

Values for soil Potassium content recorded within the same rate of Compost for each rate of applied Potassium are shown in Table 1.195. Most treatment combinations recorded values greater than 35 mg/kg, the soil level at which carrots became unresponsive to applied Potassium.

Table 1.195. Concentration of Potassium (mg/kg % db) in soil at planting

Treatment	Potassium kg/ha				
	0	50	75	125	225
Control	15	30	36	45	52
30 m^3	67	98	86	94	100
60 m^3	122	120	145	145	136

Harvest at 60 days

Density

Plant density averaged 84 plants per square metre. While this was higher than the planned 70 plants per square metre there were no treatment differences.

Total plant weight

Within the main plot stratum Compost treated plots produced less total plant weight (16.9 tonne/ha) than Control (18.2 tonne) ($P = 0.056$). The linear response of Total Plant Weight to applied Potassium was different for Compost type with Compost A showing lower production at the higher rates of applied Potassium ($P = 0.023$; Table 1.196).

Table 1.196. Total plant weight of carrots at 60 days (tonne/ha)

Treatment	*Potassium application kg/ha*				
	0	*50*	*75*	*125*	*225*
Control	*19.7*	*17.9*	*16.3*	*18.4*	*18.8*
Compost A	*17.0*	*17.5*	*16.0*	*16.6*	*16.6*
Compost B	*16.1*	*16.4*	*16.0*	*18.3*	*18.9*

lsd 5%		
	Control vs Composts	2.9
	Compost A v B	2.4
	Controls between K Levels	3.4
	Compost between K Levels	2.4

The lower Total Plant weight was the combination of a trend for compost to produce both less top ($P = 0.059$) and less root ($P = 0.069$) growth.

Harvest at 114 days

Harvest results were variable and the only plots to show less than maximum yield were Control plots receiving less than 75 kg of applied Potassium.

Top growth

There were no difference within the main plot stratum but linear response of Weight of Top to applied Potassium was different for Compost type (P = 0.023; Table 1.197). Compost A produced more Top at the higher rates of Potassium application.

Table 1.197. Top weight of carrots at 114 days (tonne/ha)

Treatment	***Potassium application kg/ha***				
	0	***50***	***75***	***125***	***225***
Control	*16.6*	*16.3*	*17.4*	*16.6*	*17.6*
Compost A	*17.6*	*17.8*	*17.9*	*19.5*	*19.2*
Compost B	*17.4*	*17.9*	*17.4*	*18.1*	*17.1*

lsd 5%	Control vs Composts	2.5
	Compost A v B	2.1
	Controls between K Levels	2.1
	Compost between K Levels	1.5

Weight of root

There was an interaction between weight of root harvested, Compost rate and applied Potassium (P = 0.037). The linear response of weight of root to applied Potassium was different for Compost rate and reflected Control plots requiring the application of 75 kg/ha of Potassium to achieve maximum yields (P = 0.004; Table 1.198).

Table 1.198. Weight of carrot root at 114 days (tonne/ha)

Treatment	***Potassium application kg/ha***				
	0	***50***	***75***	***125***	***225***
Control	*69.7*	*71.5*	*74.2*	*72.3*	*77.6*
Compost 30 m^3	*73.3*	*75.2*	*75.8*	*77.9*	*78.2*
Compost 60 m^3	*78.4*	*75.8*	*75.0*	*78.6*	*73.3*

lsd 5%	Control vs Composts	7.7
	Compost 30 m^3 v 60 m^3	6.3
	Controls between K Levels	6.2
	Compost between K Levels	4.3

Market grade A,B carrots

On average Carrots grown in Compost treated plots produced more Grade A,B carrots (49.4 tonne/ha) than Control plots (42.0 tonne) (P = 0.033). 42.8 per cent of carrots from Control plots and 35.0 per cent from Compost treated plots failed to meet this export standard (P = 0.008). Compost A recorded a lower level of rejection (P = 0.015; Table 1.199).

Table 1.199. % carrots not graded A,B

Treatment	Carrot
Control	42.8a*
Compost A	32.0b
Compost B	38.1a

* Values followed by a common subscript are not different (P > 0.05).

Plant analysis

Nitrogen content of carrot top

There was no treatment effect on the Nitrogen content of carrot top at harvest. Values were within the normal range and averaged 1.97% db.

Phosphorus content of top

Within main plots plants from Compost treated plots recorded lower Phosphorus content (0.32% db) than plants from Control plots (0.36%) (P < 0.001). Phosphorus content declined with increased application of Potassium, there was an interaction between Compost and applied Potassium and the linear response of Phosphorus content of top to applied Potassium was different for compost type (P = 0.002; Table 1.200). The trend was for compost B to give lower levels of Phosphorus at the higher rates of applied Potassium.

Table 1.200. Phosphorus content of carrot top at 114 days (% db)

Treatment	*Potassium application kg/ha*				
	0	*50*	*75*	*125*	*225*
Control	*0.43*	*0.36*	*0.38*	*0.32*	*0.32*
Compost A	*0.35*	*0.34*	*0.30*	*0.32*	*0.30*
Compost B	*0.37*	*0.36*	*0.30*	*0.29*	*0.26*

lsd 5%		
	Control vs Composts	0.037
	Compost A v B	0.030
	Controls between K Levels	0.038
	Compost between K Levels	0.027

Potassium content of top

Within the main plot stratum Potassium content of top increased with Compost rate (P = 0.002; Table 1.201). Across all main plots Potassium content increased with rate of applied Potassium (P < 0.001; Table 1.202).

Table 1.201. Potassium content of carrot top at 114 days (% db)

Treatment	Carrot
Control	1.41a*
Compost 30 m^3	1.57a
Compost 60 m^3	1.91b

* Values followed by a common subscript are not different (P > 0.05).

Table 1.202. Potassium content of carrot top at 114 days (% db)

	Potassium application kg/ha				
	0	**50**	**75**	**125**	**225**
All treatments	*0.85*	*1.26*	*1.48*	*2.00*	*2.79*

Nitrogen content of carrot root

While there were no difference within the main plot stratum there was a significant interaction between Compost and applied Potassium (P = 0.006; Table 1.203). There was a trend for Compost to increased nitrogen content of roots at higher rates of applied Potassium.

Table 1.203. Nitrogen content of carrot root at 114 days (% db)

Treatment	*Potassium application kg/ha*				
	0	**50**	**75**	**125**	**225**
Control	*1.678*	*1.520*	*1.602*	*1.425*	*1.498*
Compost A	*1.546*	*1.465*	*1.600*	*1.624*	*1.600*
Compost B	*1.535*	*1.595*	*1.471*	*1.568*	*1.531*

lsd 5%	Control vs Composts	0.12
	Compost A v B	0.10
	Controls between K Levels	0.14
	Compost between K Levels	0.10

Phosphorus content of root

While within the main plot stratum carrots from Compost treated plots contained less Phosphorus (0.48% db) than Controls (0.50%) the difference was small. Phosphorus concentration decreased with increased rate of applied Potassium (P = 0.001; Table 1.204) and the lower average concentration in carrots from the Compost treated plots logically resulted from the additional Potassium supplied by the Compost in these plots.

Table 1.204. Phosphorus content of carrot root at 114 days (% db)

	Potassium application kg/ha				
	0	**50**	**75**	**125**	**225**
All treatments	*0.498*	*0.486*	*0.478*	*0.478*	*0.468*

Potassium content of carrot root

Potassium concentration increased with rate of Compost (P < 0.001; Table 1.205) and increased with rate of applied Potassium P < 0.001; Table 1.206).

Table 1.205. Potassium content of Carrot root at 114 days (% db)

Treatment	**Carrot**
Control	1.42a*
Compost 30 m^3	1.59a
Compost 60 m^3	1.94b

* Values followed by a common subscript are not different (P > 0.05).

Table 1.206. Potassium content of carrot root at 114 days (% db)

	Potassium application kg/ha				
	0	***50***	***75***	***125***	***225***
All treatments	*1.004*	*1.375*	*1.551*	*2.035*	*2.511*

Nutrient uptake by carrot root

All treatments absorbed similar amounts of Nitrogen (118.6 kg/ha) and Phosphorus (36.8 kg/ha) into roots. The uptake of Potassium increased with Compost rate ($P < 0.001$; Table 1.207). The higher uptake was a reflection of the higher concentration in roots caused by the increased application of Potassium through the Compost.

Table 1.207. Potassium uptake by carrot root at 114 days (% db)

Treatment	Carrot
Control	106.2a*
Compost 30 m^3	123.1b
Compost 60 m^3	149.8c

* Values followed by a different subscript are different ($P < 0.05$).

Analysis of youngest fully mature leaf at harvest

Analysis of the youngest fully mature leaf at harvest is shown in Table 1.208. Compost decreased Phosphorus, Sodium and Manganese concentration.

Table 1.208. Analysis of carrot YFML at harvest

Analyt	Control	Compost	*5% lsd*	Normal range*
% db				
Phosphorus	0.32	0.29	0.03	0.3–0.4
Potassium	1.74	1.91	ns	1.3–1.5
Sodium	1.93	1.75	0.14	0.7–4.5
Calcium	2.14	2.53	ns	1.8–2
Magnesium	0.36	0.35	ns	0.35–0.40
Sulphur	0.27	0.28	ns	0.3–0.6
mg/kg				
Boron	37	36	ns	29–35
Copper	4.0	3.8	ns	5–7
Iron	1300	1590	ns	120–350
Manganese	87	47	23	190–350
Zinc	24	21	ns	20-50

* Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.

Soil analysis at harvest

Analysis of soil at harvest showed that soil K levels in all plots had fallen to below 15 mg/kg or levels similar to those recorded prior to commencement of this work (Table 1.209).

Table 1.209. Concentration of Potassium (mg/kg % db) in soil at harvest

Treatment	Potassium kg/ha				
	0	50	75	125	225
Control	< 10	10	14	12	15
30 m^3	10	11	13	11	16
60 m^3	10	11	13	11	15

Growing conditions

Crop management was good and irrigation met recommendations (Figure 1.33).

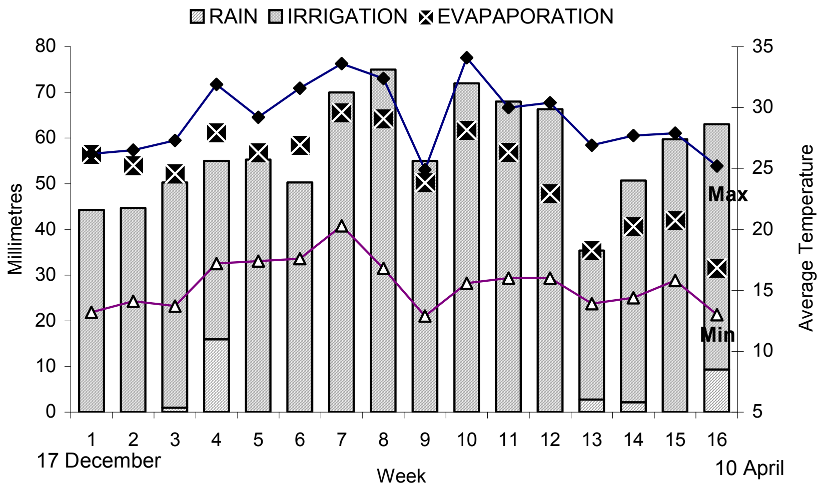


Figure 1.33 Growing conditions Crop 2 – carrots.

Discussion

The incorporation of crop residue from the previous lettuce crop and the addition of more Compost increased soil Potassium concentrations to high levels. This meant all plots, with the exception of the control plots which were to receive low rates of applied Potassium, contained sufficient Potassium for maximum growth of carrots (Table 1.195).

While harvest at 60 days showed compost had reduced growth (Table 1.196), at 114 days increased top weight was recorded in plots treated with Compost A and high rates of applied Potassium (Table 1.197). The Potassium supplied by Compost maximised carrot yield in plots receiving no applied Potassium (Table 1.198).

Carrots continued to increase the concentration of Potassium in their roots and shoots as soil and applied Potassium levels increased (Table 1.206).

The average quality of Carrots grown in Compost treated plots was better and Compost produced more Grade A,B carrots.

Lettuce - Crop 3

Iceberg lettuce seedlings, variety *Oxley*, were transplanted on 30 May 2002 and the following fertiliser treatments applied weekly by watering can for 11 weeks. The lettuce was harvested 82 days later on 20 August 2002. Intermediate growth was recorded on 16 July (47 days).

Treatment	Compost rates m^3/ha	Potassium rate kg N/ha	
Control	Nil	K1	Nil
A1/B1	30	K2	150
A2/B2	60	K3	250
		K4	350
		K5	450

Phosphorus was applied at a rate of 200 kg of P per hectare together with a complete trace element mix as a single application across the site prior to planting. All treatments received 450 kg of Nitrogen and 22 kg of Magnesium per hectare. The Potassium treatments, together with Nitrogen and Magnesium were applied by watering can as weekly applications. Week 1, 2 per cent; week 2, 4 per cent; week 3, 6 per cent; week 4, 8 per cent; week 5, 12 per cent; week 6, 15 per cent; week 7, 16 per cent; week 8, 12 per cent, week 9, 10 per cent; week 10, 10 per cent and week 11, 5 per cent of the total applied.

Compost quality

Compost A had a C/N ratio of 25, low levels of Nitrogen mainly as Nitrate and contained readily available carbon (NDI = 0.36). Compost B, which had been used as fresh compost on lettuce (crop 2) in the Phosphorus site and carrots (crop 2) in the Potassium site had matured further and its C/N ratio had fallen from 19 to 18 (Appendix 1.11 Compost 6 and 4B(2)).

Compost	Carbon Nitrogen ratio	Nitrogen drawdown index	Toxicity	Total Nitrogen	$NH_4 + NO_3$	NO_3/NH_4 ratio
Critical value	< 20	> 0.5	> 60	> 1.0	> 100	> 0.14
Compost 6A	25	0.36	90	1.3	44	19.0
Compost 4B(2)	18	0.45	91	1.7	4.2	> 1.0

Results

Harvest at 47 days

Within the main plot stratum growth increased with rate of Compost (P = 0.044; Table 1.210). Plot data was variable but on average harvest weight increased with rate of applied Potassium (P = 0.013; Table 1.211).

Table 1.210. Weight of lettuce at 47 days (tonne/ha)

Treatment	Lettuce
Control	12.77a*
Compost 30 m^3	13.94a
Compost 60 m^3	15.01b

* Values followed by a common subscript are not different (P > 0.05).

Table 1.211. Weight of lettuce at 47 days (tonne/ha)

	Potassium application kg/ha				
	0	***75***	***125***	***175***	***225***
All treatments	*13.34*	*13.91*	*14.42*	*14.59*	*14.42*

Harvest at 82 days

Within the main plot stratum total weight of lettuce harvested increased with rate of Compost (P = 0.01; Table 2.211). There was an interaction between treatment with Compost and applied Potassium and the response of total weight harvested to applied Potassium was different for Control and the average of Compost treated plots (P < 0.001; Table 1.212).

Table 1.210. Weight of lettuce at 82 days (tonne/ha)

Treatment	Lettuce
Control	59.94a*
Compost 30 m^3	67.51b
Compost 60 m^3	72.74c

* Values followed by a different subscript are different (P < 0.05).

Table 1.212. Weight of lettuce at 82 days (tonne/ha)

Treatment	***Potassium application kg/ha***				
	0	***150***	***250***	***350***	***450***
Control	*37.82*	*60.77*	*63.59*	*65.89*	*71.63*
Compost	*58.33*	*68.65*	*71.94*	*75.56*	*76.11*

lsd 5%	Control vs Compost	6.06
	Controls between K Levels	6.59
	Compost between K Levels	3.29

Processed head

The percentage of processed head (53.7% of total weight) was similar for all treatments and the treatment relationships for weight of processed head were similar to those established for total plant weight (P = 0.008; Table 1.213).

Table 1.212. Weight of processed head at 82 days (tonne/ha)

Treatment	***Potassium application kg/ha***				
	0	***150***	***250***	***350***	***450***
Control	*20.63*	*32.56*	*33.63*	*37.71*	*40.19*
Compost	*30.18*	*36.41*	*38.12*	*41.84*	*41.14*

lsd 5%	Control vs Compost	3.99
	Controls between K Levels	5.01
	Compost between K Levels	2.50

An exponential curve fitted to the plot data for total weight to lettuce harvested and grouped for rate had a probability of < 0.001 and accounted for 70.4 per cent of the observed variance (Figure 1.34). The relationship of total weight of lettuce harvested at 82 days was described by the functions:

Control $= 73.12 - 34.61*(0.99443)^{\wedge Potassium}$
Compost 30 m^3 $= 76.19 - 22.82*(0.99443)^{\wedge Potassium}$
Compost 60 m^3 $= 78.86 - 16.09*(0.99443)^{\wedge Potassium}$

The amount of applied Potassium required to achieve 95 per cent of the maximum yield was 406 kg/ha for the control, 324 kg for plots which had received 30 m^3 of compost and 254 kg for 60 m^3. The higher values, on average 37 kg more than those calculated from the first crop, are consistent with this being a winter crop and support the finding that the K in compost is freely available. By calculation 100 kg of Potassium supplied by compost was equivalent to 120 kg supplied as the nitrate. The functions also predict a 3–5 tonne per hectare yield benefit from using compost.

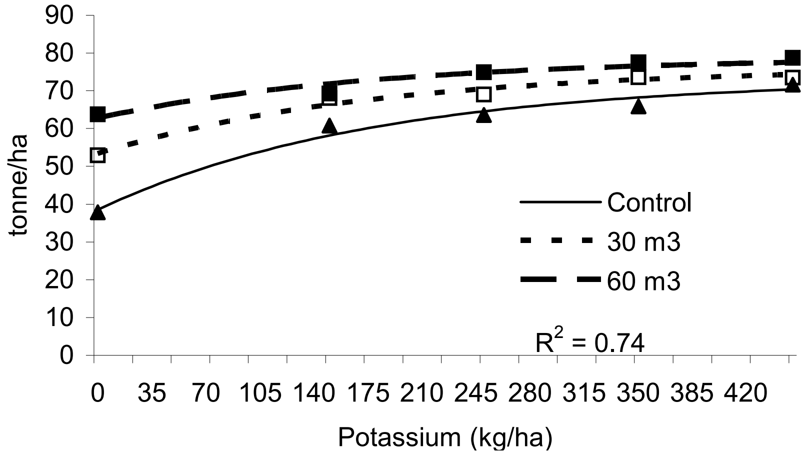


Figure 1.34. Response of total weight of lettuce harvested to applied Potassium and Compost rate.

Plant analysis

Nitrogen

Nitrogen content of lettuce at harvest showed a quadratic response to applied Potassium ($P < 0.001$; Table 1.213).

Table 1.213. Nitrogen content of lettuce at 82 days (mg/kg db)

	Potassium application kg/ha				
	0	***150***	***250***	***350***	***450***
All treatments	*3.731*	*4.122*	*4.152*	*4.218*	*4.096*

Phosphorus

While there were no differences within the main plot stratum for Phosphorus content the response of Phosphorus content to applied Potassium for Control plots was different to the average of the Compost treated plots ($P = 0.017$; Table 1.214). The trend was for Compost treated plots to give higher Phosphorus content at the low application rates of applied Potassium.

Table 1.214. Phosphorus content of lettuce at 82 days (mg/kg db)

Treatment	***Potassium application kg/ha***				
	0	***150***	***250***	***350***	***450***
Control	*0.578*	*0.688*	*0.750*	*0.725*	*0.750*
Compost	*0.658*	*0.714*	*0.718*	*0.748*	*0.717*

Potassium

Potassium content increased with Compost rate (P = 0.011; Table 1.215) and increased with rate of applied Potassium (P < 0.001; Table 1.216). Large variation meant differences between Control and Compost treated plots were not significant but values were generally above the normal range.

Table 1.215. Potassium content of Lettuce at 82 days (mg/kg db)

Treatment	Carrot
Control	4.179a*
Compost 30 m^3	4.674a
Compost 60 m^3	5.065b

* Values followed by a common subscript are not different (P > 0.05).

Table 1.216. Potassium content of lettuce at 82 days (mg/kg db)

	Potassium application kg/ha				
	0	***150***	***250***	***350***	***450***
All treatments	*1.442*	*3.610*	*4.944*	*6.379*	*7.282*

Plant uptake

Within the main plot stratum the better growth of plots treated with compost resulted in higher average plant uptake of Nitrogen, Phosphorus and Potassium by Compost treated plots (Table 1.217).

Table 1.215. Uptake of nutrients by lettuce at 82 days (kg/ha)

Treatment	Nitrogen	Phosphorus	Potassium
Control	120.6a*	20.37a	126.3a
Compost 30 m^3	131.9b	23.23b	155.3b
Compost 60 m^3	138.3b	24.17b	174.3c

* Values followed by a common subscript are not different (P > 0.05).

Nitrogen uptake

The quadratic response of plant uptake of Nitrogen to applied Potassium was different for compost type and there was a trend for Compost A to take up more nitrogen at most levels of applied Potassium (P = 0.031; Table 1.216).

Table 1.216. Nitrogen uptake by lettuce at 82 days (kg/ha)

Treatment	*Potassium application kg/ha*				
	0	*150*	*250*	*350*	*450*
Control	*84.8*	*125.7*	*131.3*	*127.6*	*134.2*
Compost A	*117.6*	*138.5*	*136.9*	*145.6*	*135.4*
Compost B	*117.7*	*130.7*	*134.0*	*141.0*	*153.6*

lsd 5%		
	Control vs Composts	17.1
	Compost A v B	13.9
	Controls between K Levels	19.5
	Compost between K Levels	13.8

Phosphorus uptake

There was an interaction (P = 0.008) between compost treatment and applied Potassium for plant uptake of Phosphorus and the linear response of Phosphorus uptake to applied Potassium was different for Control and the average of Compost treated plots (P = 0.004; Table 1.217). This higher uptake by compost treated plots was a result of higher growth and higher Phosphorus concentration which arguably resulted from the better Potassium nutrition of these plots.

Table 1.217. Phosphorus uptake by lettuce at 82 days (kg/ha)

Treatment	*Potassium application kg/ha*				
	0	*150*	*250*	*350*	*450*
Control	*13.38*	*20.55*	*22.19*	*21.60*	*24.11*
Compost	*20.57*	*23.35*	*23.76*	*25.51*	*25.31*

lsd 5%		
	Control vs Compost	2.53
	Controls between K Levels	3.14
	Compost between K Levels	1.57

Potassium uptake

Plant uptake of Potassium increased with rate of applied Potassium and there were no significant differences in the sub plot stratum (P < 0.001; Table 1.218).

Table 1.218. Potassium uptake by lettuce at 82 days (kg/ha)

	Potassium application kg/ha				
	0	*150*	*250*	*350*	*450*
All treatments	*44.1*	*116.6*	*160.5*	*212.1*	*253.5*

Relationship of plant potassium content and growth

An exponential curve fitted to the plot data for concentration of Potassium and weight of lettuce harvested and grouped for Compost rate had a probability of < 0.001 and accounted for 68.4 per cent of the observed variance. This suggested that factors other than the Potassium supplied by Compost influenced yields (Figure 1.35).

The weight of lettuce harvested was described by the functions:

Control = 68.69 – 43.61*0.5866^Potassium Concentration

Compost 30 m^3 = 74.23 – 43.61*0.5866^Potassium Concentration

Compost 60 m^3 = 78.19 – 43.61*0.5866^Potassium Concentration

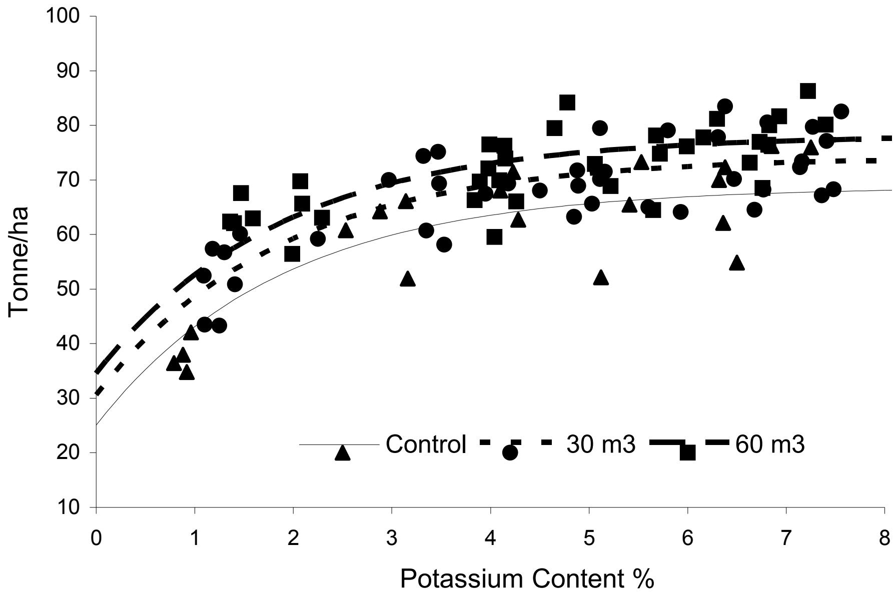


Figure 1.35. Effect of concentration of Potassium and Compost rate on weight of lettuce harvested.

Soil bicarbonate extractable Potassium at planting

The incorporation of the carrot top residue and the application of compost increased soil Bicarbonate Potassium content. Within the main plot stratum Potassium increased with Compost Rate ($P < 0.001$; Table 1.219). There was an interaction between Compost type and previously applied Potassium and the increase in soil Potassium with increased application of previously applied Compost was different for Compost Type ($P = 0.006$; Table 1.220). Compost B treated plots recorded higher levels of Bicarbonate extractable Potassium.

Table 1.219. Potassium content of soil at planting (mg/kg db)

Treatment	Lettuce
Control	20.60a*
Compost A	41.30b
Compost B	44.60b

* Values followed by a common subscript are not different ($P > 0.05$).

Table 1.220. Potassium content of soil at planting (mg/kg db)

Treatment	***Previous Potassium application kg/ha***				
	0	***150***	***250***	***350***	***450***
Control	*19.8*	*18.5*	*19.8*	*22.8*	*22.2*
Compost A	*39.5*	*42.0*	*40.5*	*38.2*	*46.2*
Compost B	*38.2*	*38.2*	*43.6*	*51.0*	*51.9*
lsd 5%	Control vs Composts		9.00		
	Compost A v B		7.35		
	Controls between K Levels		9.3		
	Compost between K Levels		6.6		

Soil bicarbonate extractable Potassium at harvest

Soil Potassium in plots receiving low rates of applied Potassium had declined dramatically at harvest and while it increased with previously applied Potassium there were no main plot effects ($P < 0.001$; Table 1.221).

Table 1.221. Potassium content of soil at harvest (mg/kg db)

	Potassium application kg/ha				
	0	***150***	***250***	***350***	***450***
All treatments	*9.7*	*17.4*	*25.0*	*37.8*	*51.6*

Growing conditions

Growing conditions were typical of winter and rainfall and irrigation met crop water requirements (Figure 1.36).

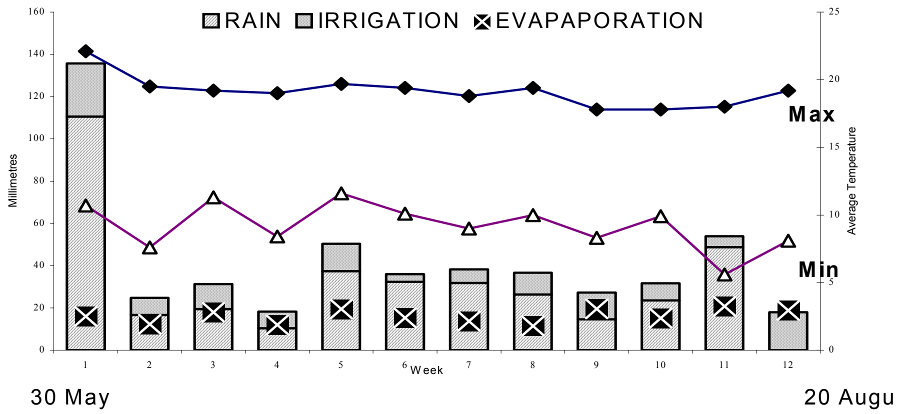


Figure 1.36. Growing conditions lettuce – Crop 3.

Analysis of youngest fully mature wrapper leaf at harvest

Leaf analysis at harvest showed Calcium and Copper concentrations were below the normal range. Compost increased Phosphorus, Calcium and Magnesium levels but decreased Sodium, Manganese and Zinc (Table 1.222).

Table 1.222. Analysis of lettuce wrapper leaf at harvest

Analyt	Control	Compost	*5% lsd*	Normal range*
% db				
Phosphorus	0.56	0.59	0.03	0.55–0.65
Potassium	> 4.0	> 4.0		5.5–6.0
Sodium	0.80	0.70	0.05	0.5–1.0
Calcium	0.97	1.11	0.08	1.4–2.0
Magnesium	0.32	0.35	0.027	0.3–0.7
Sulphur	0.34	0.32	ns	0.3–0.32
mg/kg				
Boron	26.0	26.0	ns	25–55
Copper	4.4	4.4	ns	10–18
Iron	463	425	ns	50–500
Manganese	108	66	7.2	50–300
Zinc	79	54	Ns	30–100

* Reuter, D.J. and Robinson, J.B. Plant Analysis second edition CSIRO Publishing 1997.

Discussion

The response of plant growth to applied Potassium was different for Control and Compost treated plots. This was not fully explained by the additional Potassium supplied by the Compost and an additional "Compost" response was recorded (Table 1.212 and Figures 1.34 and 1.35).

The Potassium in Compost was freely available and Compost had a sparing effect on the quantity of Potassium required to achieve 95 per cent of maximum yield. This showed that when calculating fertiliser application requirements 100 kg of Potassium contained in Compost will substitute for 120 kg of Potassium supplied as nitrate.

Conclusions – Potassium site

The availability of potassium contained in compost is totally available when applied to a site that had not previously received compost. Further at the first application, compost was able to reduce the potassium requirement maximum yield by between 15 and 20%.

In the final crop grown during winter when impacts of rainfall on leaching are potentially greater, compost reduced the potassium requirement by 20%.

Soil quality

Assessment of soil quality was largely investigated at the Nitrogen Replacement site because of the longer history of compost applications associated with the seven trials.

Bulk density and volumetric water

Soil Bulk Density and Volumetric Water was determined after 1, 3 and 7 applications of compost using metal cores 6 cm in diameter and 5 cm deep (Manual of Field Techniques in Hydrology, Department of Agriculture Misc. publication 37/91).

A single application of compost had no significant effect on Soil Bulk Density, 1.401 tonne/m^3 and Volumetric Water, 9.12 per cent when the soil was sampled 2 weeks after planting.

After 7 applications compost had reduced Soil Bulk Density (Figure 1.37A) and increased Volumetric water 20 (30 m^3) and 40 (60 m^3) per cent (Figure 1.37B).

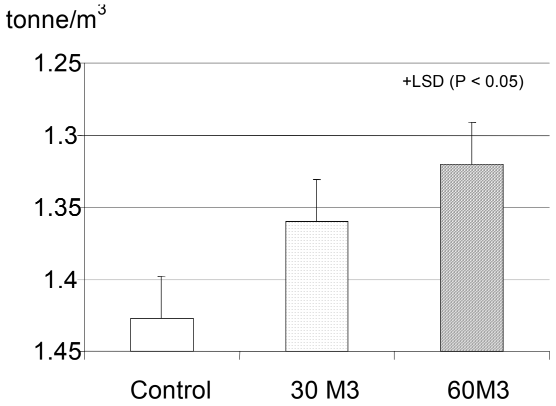


Figure 1.37A. Soil bulk density after 7 crops and compost applications.

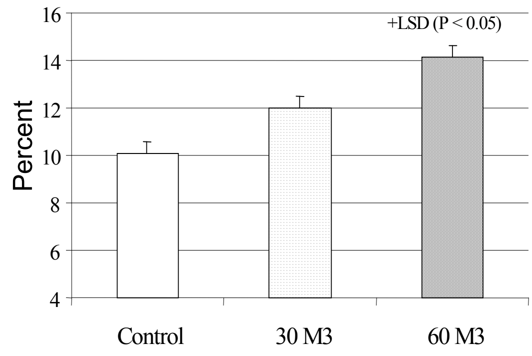


Figure 1.37B. Volumetric water holding capacity after 7 crops.

Soil pH

Compost stabilised soil pH (Figure 1.38).

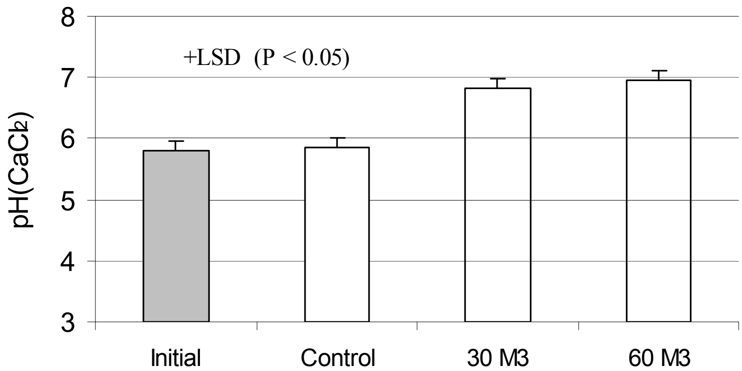


Figure 1.38. Soil pH after seven crops at the Nitrogen replacement trial site.

Cation exchange

Compost application increased the cation exchange capacity of the soil (Figure 1.39). Values achieved approached those typical of red brown earths (K. Peverill *et al.* Soil Analysis, an interpretation manual).

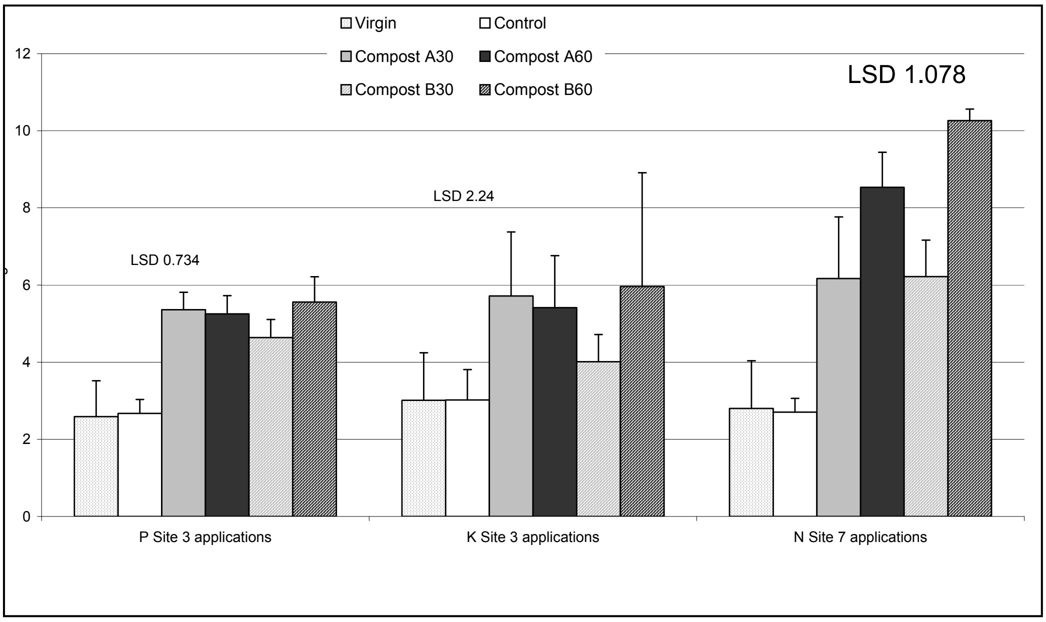


Figure 1.39. Exchangeable cations (sum of Calcium, Magnesium, Potassium and Sodium).

Soil organic carbon

Soil carbon in the top 15 cm of soil increased with the continued use of compost but appeared to stabilise after 5 applications (Figure 1.40).

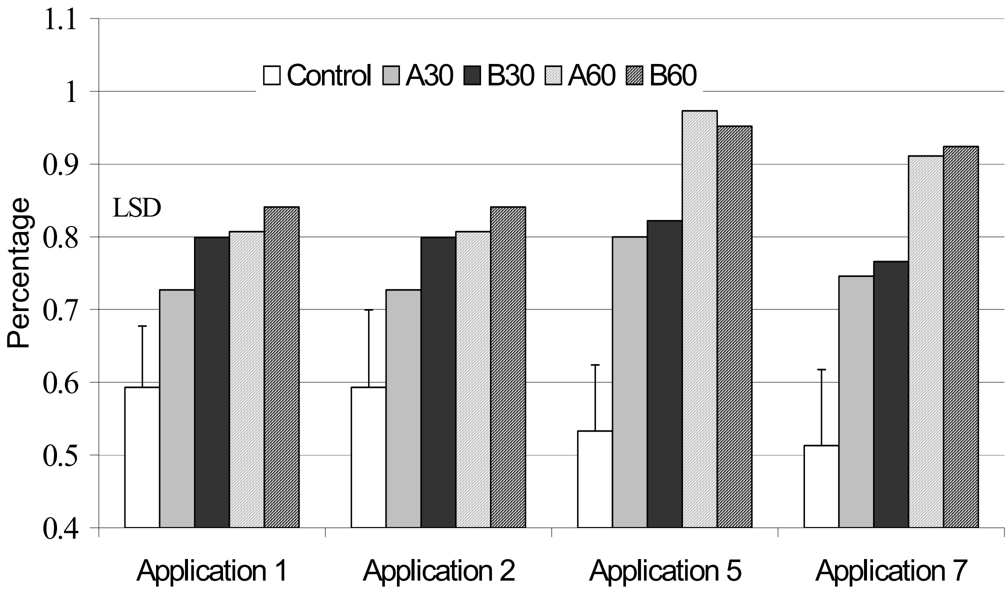


Figure 1.40. Soil carbon (% db) after selected compost applications at the Nitrogen replacement trial site.

Analysis at completion of the trials revealed that carbon levels had increased throughout the soil profile and it was calculated that approximately 30 per cent of the carbon applied had been retained in the soil profile (Figure 1.41).

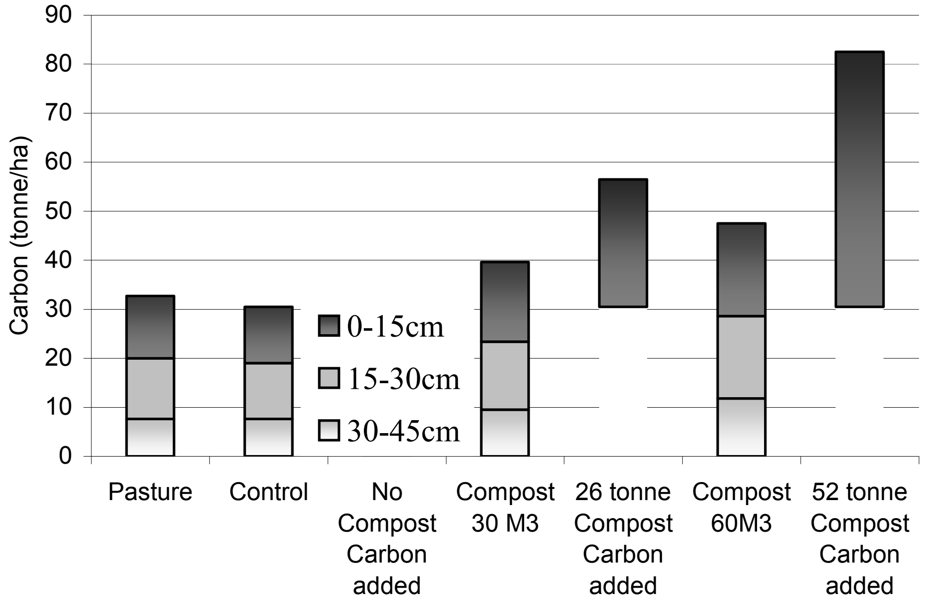


Figure 1.41. **Quantity of soil carbon after seven compost applications at the Nitrogen replacement trial site.**

Soil nitrogen

Soil nitrogen increased with compost addition but stabilised in the top 15 cm soil after 3 applications (Figure 1.42).

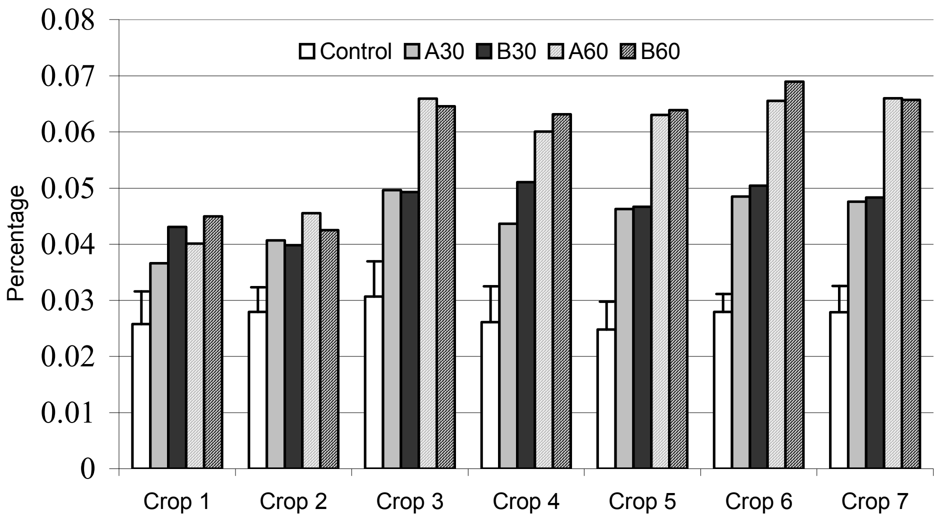


Figure 1.42. **Total soil Nitrogen (% db) after seven consecutive compost applications at the Nitrogen replacement trial site.**

Analysis of soil at completion of the trials showed that nitrogen had moved down the soil profile and it was calculated that soil nitrogen had increased by an amount equivalent to 90 per cent of the nitrogen applied by the compost, for plots receiving 30 m^3, and 80 per cent for plots receiving 60 m^3 rates of application. There had been almost no increase of soil nitrogen in the control plots despite the accumulated application of 2,500 kg of Nitrogen fertiliser (Figure 1.43).

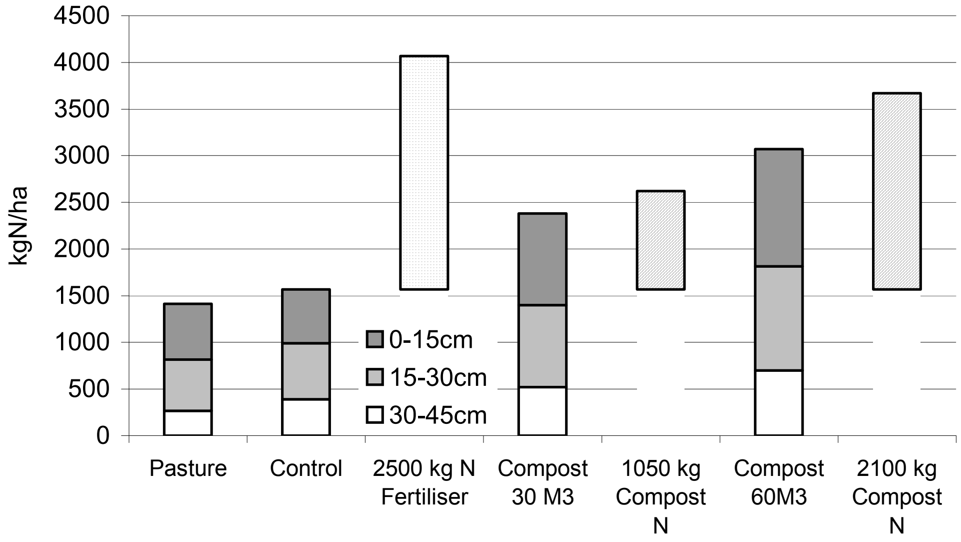


Figure 1.43. **Total soil Nitrogen (kg N/ha) after selected compost applications at the Nitrogen replacement trial site.**

The increase in soil nitrogen meant that the Carbon Nitrogen Ratio of the compost treated soil improved dramatically over the course of the trials (Figure 1.44).

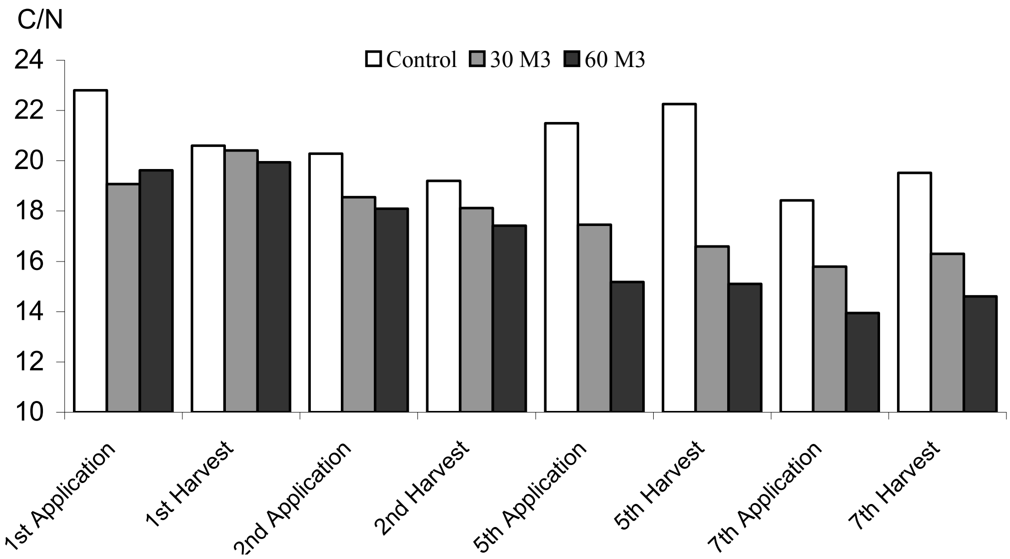


Figure 1.44. **Soil carbon Nitrogen ratio (0-15 cm) after selected compost applications at the Nitrogen replacement trial site.**

Soil nitrogen as nitrate at planting and harvest

While Soil Nitrate varied with crop and season some composts increased the level of soil nitrate at planting. The increased plant availability of nitrogen at the time of planting is considered to be the primary cause of the plant responses recorded with transplanted crops (Figures 1.45 and 46).

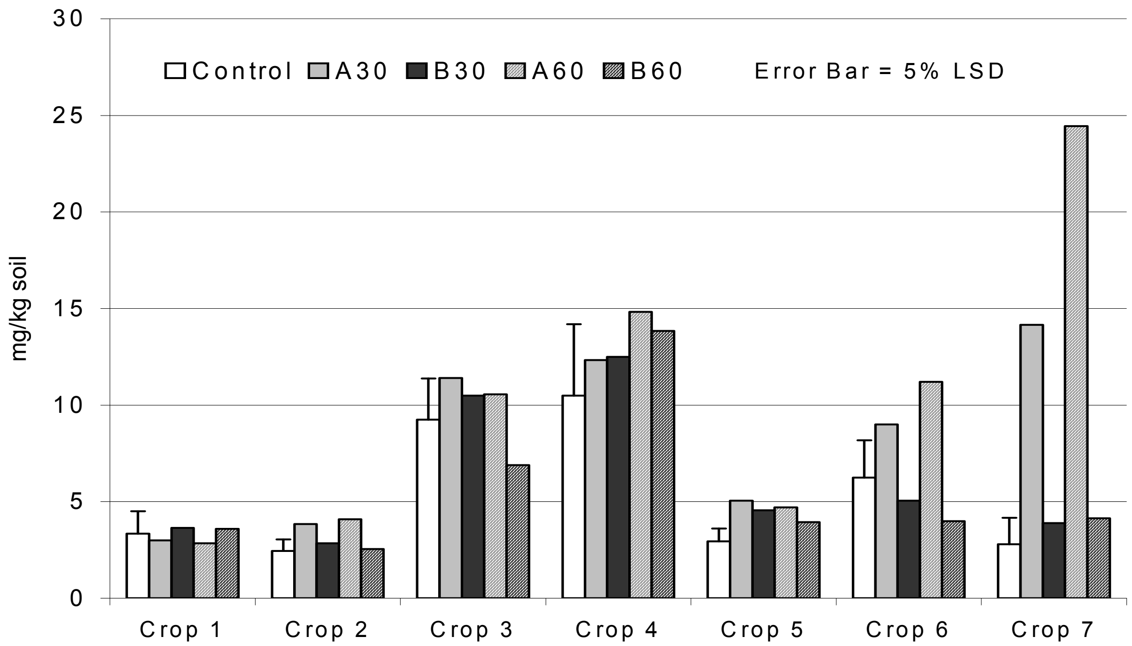


Figure 1.45. Nitrate Nitrogen after seven consecutive compost applications at the Nitrogen replacement trial site.

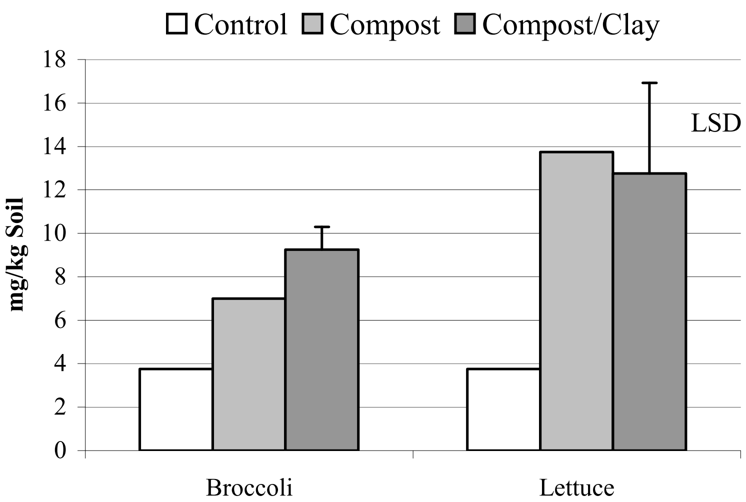


Figure 1.46. Nitrate Nitrogen at planting of Crop 3 and Crop 5 at the system site.

Discussion

The continued use of compost increased soil Carbon, Nitrogen and Total Exchangeable Cations. It reduced bulk density and stabilised pH and increased the fertility of the soil.

Plant responses to the use of compost were recorded when nitrogen mineralisation was stimulated and soil nitrate nitrogen levels were elevated at planting. While compost quality was obviously an important determinate in the magnitude of the crop response recorded there was evidence that the response increased as soil Carbon and Nitrogen levels increased with the continued use of Compost.

Appendix 1.1. Analysis of the compost used in the Fertiliser replacement trial site at the Medina Research Station. Samples were collected immediately before compost application and analysed to AS 4454 specifications by Collex Laboratories, Adelaide, SA.

Analyte	Critical/ ideal value	Unit	Compost batch (1A- 4A) and additional composting (B)								
			Compost 1A	Compost B	Compost 2A	Compost 1B	Compost 3A	Compost 2B	Compost 4A	Compost 2B	Compost 4B(2)
Carbon Nitrogen Ration	< 20/< 17	none	28	21	31.0	28.0	19	25	19	21	18
Nitrogen Drawdown Index	> 0.5	none	0.21	0.50	0.34	0.26	0.30	0.29	0.44	0.54	0.45
Organic matter		% DM	62	56	69	66	55	56	51	58	51
pH ($CaCl_2$)	5 - 7.5	pH units	7.6	7.5	7.8	7.6	7.6	7.8	7.5	7.9	7.7
Electrical conductivity	-	dS/m	2.10	2.75	2.80	1.55	3.40	2.60	3.95	2.00	2.45
Toxicity (potting mix test)	> 60	%	55	57	98	95	86	90	100	81	91
Moisture content	> 35	n/a	50	45	44	49	44	44	45	51	
Total Nitrogen	> 1.0/1.4	% DM	1.3	1.5	1.3	1.4	1.7	1.3	1.6	1.6	1.7
NH_4 + NO_3	> 100	mg/L	< 1.0	< 1.0	23	< 1.0	< 1.0	< 1.0	89	< 1.0	4.2
NH_4 nitrogen		mg/L	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
NO_3/NH_4 ratio	> 0.14	(m/l)	< 0.1	< 0.1	> 1	< 0.1	< 0.1	< 0.1	> 1	< 0.1	> 1
Phosphorous - Total (P)		% DM	0.6	1.3	0.6	0.7	1.1	0.8	1.0	1.0	
Phosphorus - Soluble	< 0.5	mg/L	6.02	14	8.5	11	5.7	12	5.9	10	
Potassium (K)		% DM	0.54	0.76			0.61	0.55	0.66	0.69	
Calcium (Ca)		% DM	6.4	10.2			8.6	6.4	8.9	6.7	
Magnesium (Mg)		% DM	0.26	0.39			0.37	0.32	0.4	0.38	
Manganese (Mn)		mg/kg	120	280			160	150	180	200	
Zinc (Zn)		mg/kg	140	350			200	160	200	200	
Copper (Cu)		mg/kg	56	190			130	52	140	53	

Appendix 1.1 continued …

Analyte	Critical/ ideal value	Unit	Compost batch (5A- 9A) and additional composting (B)							
			Compost 5A	**Compost 6A**	**Compost 7A**	**Compost 6B**	**Compost 8A**	**Compost 6B(1)**	**Compost 9A**	**Compost 6B(2)**
Carbon Nitrogen Ration	< 20/< 17	none	24	25	20	25	27	12	19	17
Nitrogen Drawdown Index	> 0.5	none	0.68	0.36	0.51	0.37	0.41	< 0.10	< 0.10	0.20
Organic matter		% DM	51	55	46	51	50	55	46	37
pH ($CaCl_2$)	5 - 7.5	pH units	8	6.8	7.6	7.8	7.4	7.6	7.3	7.9
Electrical conductivity	-	dS/m	2.25	3.25	2.90	1.35	4.10	1.55	6.85	4.00
Toxicity (potting mix test)	> 60	%	74	90	79	100	74	78	< 5.0	67
Moisture content	> 35	n/a	38	39	47	43	35	43	30	32
Total Nitrogen	> 1.0/1.4	% DM	1.2	1.3	1.4	1.2	1.1	2.7	1.4	1.3
NH_4 + NO_3	> 100	mg/L	27	44	140	78	50	< 1.0	110	33
NH_4 nitrogen		mg/L	27.0	2.2	140.0	78.0	< 1.0	< 1.0	55.0	3.3
NO_3/NH_4 ratio	> 0.14	(m/l)	< 0.1	19.00	< 0.10	< 0.10	> 1	< 0.1	0.93	9.10
Phosphorous - Total (P)		% DM	0.5	0.5	0.6		0.5		0.9	0.6
Phosphorus - Soluble	< 0.5	mg/L	3.9	4.4			1.7		2.2	< 1.0
Potassium (K)		% DM	0.43	0.33	0.54	0.36			0.66	0.44
Calcium (Ca)		% DM	9.4	9.7	12.0	10.0			6.6	7.5
Magnesium (Mg)		% DM	0.3		0.34	0.29			0.3	0.33
Manganese (Mn)		mg/kg	110	290	120		160			
Zinc (Zn)		mg/kg	120	120	140		180			
Copper (Cu)		mg/kg	87	77	100		75			

Compost 6B(1): INCORRECT ANALYSIS

Compost 6B(1): Non-correctable analysis problems, values should be between 6B and 6B(2).

SECTION 2 – FERTILISER REPLACEMENT TRIALS – VICTORIA

Introduction

In Victoria, project resources were sufficient enough only for the establishment of one fertiliser replacement trial. This was established as an N-replacement trial due to the fact that the dynamics of N supply from compost is perhaps the most important factor governing the suitability of compost for vegetable production. Whilst compost should not be considered as a fertiliser as such, its successful use in vegetable production is contingent on its quality with respect to N supply. As a minimum, compost should not compete with a crop for available N. If high quality compost is applied on a regular basis, then N supply from soil reserves becomes significant and the rates of inorganic fertiliser could be decreased. In this way, the cost of competitiveness of compost will be further increased.

A simple and reliable method of measuring N availability in compost is not yet available, but there are many measures of compost quality which help to give us clues about the potential suitability of a compost for vegetable production. There are many examples of recent reviews covering different methods of measuring compost quality (e.g. Scaglia *et al.* 2000; Tomati *et al.* 2000). Some basic parameters of compost quality are covered in the Australian Standard for compost (AS4454). These measures together with field studies should give a good overall picture of the compost quality specifications required for vegetable production.

Materials and Methods

Brief description of site at DPI Knoxfield

The farm site allocated for the compost trial was previously used for a number of years to grow a mixture of fruit (apricot trees, strawberries) and vegetables (cabbage, broccoli and celery). Soil drainage is assisted by the gentle north-facing slope and the apart from a row of 10 m Australian cypress pines (*Callitris* sp.) located eight metres from the western plot boundary, site is exposed to all weather conditions. These trees start to impart shade on the trial area at 3.00 p.m. in autumn (see Figure 2.1 below).

Soil type and description

A comprehensive soil analysis was taken 14 months prior to the initial planting of this trial. The soil colour description was yellowish, greyish, brown consisting of a fine sandy clay loam texture. The soil analysis showed the gravel content to be approximately 5 per cent and the pH to be strongly acidic. Saturated extract conductivity (Ece) was 1.8 dS/m which may harm sensitive plant species and total soluble salts was 0.06 per cent which is slightly higher than normal. The total organic matter was moderate at 4.4 per cent. Ground burnt agricultural (GBA) lime was applied to the soil prior to transplanting broccoli seedlings in order to raise the pH to 6.0-7.0. This was also a precautionary measure to help prevent club root disease in brassicas (*Plasmodiophora braccicae*).

Dimensions of trial area

Two compost trials, titled nutrient replacement (NR) trial and systems (S) trial were held next to one another and located on the farm site, a short walk from the main buildings at DPI Knoxfield (see Figure 2.1 below). The total area for both trials was 2112 m^2 (33 m x 64 m) with the NR-trial being approximately three times as large as the S-trial. Two buffer rows were allocated to the outsides of the trial area on the western and eastern edges. Similarly, extra seedlings were planted at the ends of each row on the northern and southern sides to act as buffers to the experimental plots.

Site set-up

Generally, the trial area was ploughed over one to two weeks prior to planting. Beds were raised with a disc-plough and roughly formed so that the compost could be applied on top, raked out and incorporated into the soil by rotary hoeing 1 to 5 days before planting. GBA lime was applied at 1.5 t/ha prior to adding the compost and allowed to stabilise for three days. The trial plot was then sprayed with the appropriate pre-emergent herbicide (Dual Gold for broccoli and Stomp 330E for lettuce) either before or within one week of transplanting.

Two rows of vegetables were planted per bed. Plot signs were installed and the irrigation (overhead sprinklers) set up and turned on within 2-3 days of transplanting depending upon rain. Seedlings were then side-dressed within one week with an NPK fertiliser with a further two side-dressings of nitrogen applied at 1/3 intervals over the life of the crop. After harvest soil samples and the appropriate soil tests were performed and the entire trial site ploughed in. To improve drainage and aeration a deep ripper was used at the end of each trial that displaced soil in the furrows up on top of the beds.

The site was serviced by a large dam and a pump house located approximately 300 m to the north. The pump was manually operated, generally on consecutive working days (Monday, Wednesday and Friday) or upon request. Irrigation piping was connected to three rows of overhead sprinklers (two servicing the NR-trial and one to the S-trial). Within a row, there were seven sprinkler heads located 9 m apart. Each sprinkler had an irrigating radius of approximately four beds hence there were eight beds between any two rows of sprinklers.

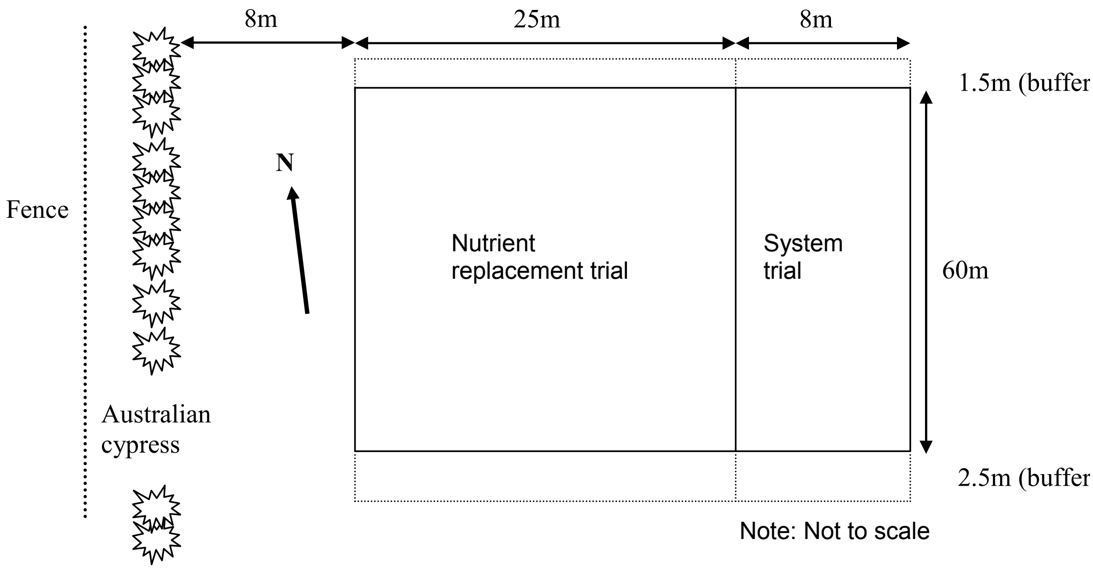


Figure 2.1. Plan view of nutrient replacement and systems compost trials at DPI Knoxfield.

N-replacement trial

Trial design

A type of split-plot design was used with six replicates laid out as 3 by 2 blocks (or repetitions). Each block contained five main plots corresponding to the five compost treatments plus the control (i.e. no compost and two types of compost, both at 35 m^3/ha and 70 m^3/ha). Each main plot contained five sub-plots which related to the five rates of nitrogen fertilisers (e.g. 0, 40, 80, 120, 160 kg/ha for broccoli) hence there were 25 treatments per block and 150 plots in total.

Table 2.1. Treatment description and application rates of compost and fertilisers for broccoli in the NR-trial

Abbreviation[1]	Compost	Rate (m^3/ha)	N-fertiliser rate (kg/ha)				
Control (n)	None	0	0	40	80	120	160
FWC35(n)	Food waste	35	0	40	80	120	160
FWC70(n)	Food waste	70	0	40	80	120	160
SGW35(n)	Soft green waste	35	0	40	80	120	160
SGW70(n)	Soft green waste	70	0	40	80	120	160

[1] e.g. Control(0) - no compost and 0 kg/ha of N; FWC70(80) - FWC at 70 m^3/ha and 80 kg/ha of N.

Trial set-up and maintenance

Two types of composts were used (soft green waste (SGWC) and food waste (FWC)) which were ordered a few weeks prior to application from the same suppliers each time. SGWC was derived from kerb-side green waste collections using wheelie bins and consisted of grass, leaves, weeds, small prunings and a little water. There was little woody material present. The FWC consisted mainly of supermarket fruit and vegetable waste, blended with sawdust and shredded mulch.

The compost was measured out by filling up the appropriate amount in one or two 20 L white buckets before being applied to individual plots, raked out and rotary hoed in by tractor.

Two pre-emergent herbicides were used. Dual Gold (960 g/L S-Metalochlor) was applied to broccoli by a tractor mounted boom spray at approximately 4 L per hectare either prior to or within one week of transplanting. This was then watered in for 1-2 hours with overhead sprinklers or by rain. Similarly Stomp 330E (330 g/L Pandemethalin) was applied prior to transplanting lettuce at approximately 4 L per hectare in a similar fashion.

For the first crop, a Hamilton tree-planter was used to hand plant 4,800 broccoli seedlings. For the remaining three crops a cup-transplanter was used to mechanically plant the broccoli and lettuce seedlings.

All four crops were affected in some way by either pests (birds, slugs, Diamondback moth, *Plutella xylostella*) or diseases White Blister Rust (*Albugo candida*) in part due to the drought in Victoria. Having a large and abundant supply of fresh water in the nearby dam attracted large flocks of birds which also attacked the crop, especially in the plots closest to the dam. This set some vegetables back 1-3 weeks. In more affected areas, some vegetables appeared to be roughly the same size at the end of the trial as they did at the start. Fortunately, only the outer leaves were nibbled in both lettuce trials, which left the hearts to grow on. After an attack, the lettuce seedlings were fertilised to help the plants to recover.

Mesurol 750 (750 g/kg Methiocarb) from Bayer was applied at 5.5 kg per hectare by hand to prevent slug and snail damage especially to lettuce. The insecticide was applied to both lettuce crops as they grew closer to the ground and were more likely to harbour pests such as slugs. Vegetable rows on the western side of the trial appeared to be more affected by slugs probably due to more shade imparted by the cypress trees in autumn and winter.

Ridomil Gold MZ (750/kg Mancozeb plus 40 g/kg Metalaxyl-M) was applied at 250 g/100 L water to prevent white blister and the biological insecticide, Delfin WG (850 g/L *Bacillus thuringiensis*) at 25 g/100 L water to control Diamondback moth that both appeared later in the second broccoli crop.

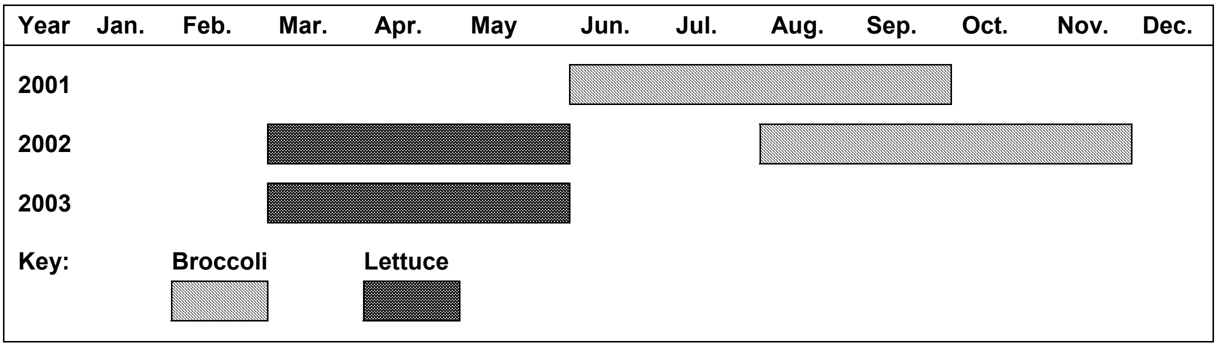
Three types of granular fertilisers (NPK) were used as either a basal application or side-dressings for both broccoli and lettuce. Nitrogen in the form of urea (46%), phosphorous as single superphosphate (8.8%) and potassium as potassium sulphate (41%) were all measured into small plastic containers in the laboratory. Approximately half of the fertiliser was applied down either row of vegetables within a plot. For best results the fertilisers were applied before either rain or irrigation. Two different standard rates of nitrogen fertilisers were used for both trials (0, 40, 80, 120 and 160 kg/ha for broccoli and 0, 30, 60, 90 and 120 kg/ha for lettuce).

Crop sequence

The following crop sequence was used: Broccoli I – Lettuce I – Broccoli II – Lettuce II (Table 2.2).

Two different varieties of vegetable seedlings were used for both broccoli (Marathon, Legacy) and lettuce (Musketeer, Casino) trials. The seedlings were ordered from the same seedling supplier several weeks prior to planting so varieties were limited to what was in stock during each season. Unfortunately, both crops of lettuce were affected by weeds due to an incorrect application rate of the recommended pre-emergent herbicide (Stomp) and cool, damp weather. Consequently the first lettuce crop was severely affected by weeds which helped introduce other pests (slugs) and diseases such as sclerotinia, pythium and botrytis. On the second crop, the entire trial area had to be levelled and reformed before transplanting due to an error in bed preparation. This brought other weed seeds up from underneath the surface and was difficult to control other than by hand weeding. The herbicide used did not specifically target cape-weed.

Table 2.2. Planting sequence and timetable for vegetable growing period only



Dimensions of trial area

The trial consisted of 16 beds (including one buffer bed) approximately 25 m in width and approximately 60 m in length which ran north-south (Figure 2.1). At each end, several buffer plants were planted to help protect the end plots. There was also a buffer row on the western side of the trial, next to grass and within eight metres of a row of Australian cypress pines. Each row contained approximately 300 plants. Bed widths were approximately 0.9 m wide with 0.5-0.6 m furrows. The bed area of each plot measured 5.4 m^2 (6.0 m x 0.9 m).

Assessments

Compost analysis

A minimum 6 L of compost samples were taken from the delivered compost. The bag was sealed and stored in a cool dry place until delivery to DPI Werribee (formerly the State Chemistry Laboratory) for analysis according to AS4454.

Soil analysis

Soil samples from the top 0-10 cm were taken from designated plots with a hand spade within one week of final harvest. One to two scoops of soil was taken from three different positions along the middle of the plot and carefully placed in a snap lock bag, sealed and transferred to the 4ºC cool room within 45 minutes of sampling. It was taken to the analytical laboratory (DPI Werribee) in an esky with ice for analysis within three days of sampling.

Leaf analysis

Leaf samples were taken from three crops in order to measure SAP nitrate content. In the first broccoli crop SAP was taken mid cycle whereas for the last broccoli and lettuce crops they were taken closer to harvest. The most recent fully developed leaf from five separate plants was harvested, placed in a snap lock bag and chilled in the field in an esky with ice. With lettuce, the outer wrapper leaf was used. Leaf samples were then transferred to a -20ºC freezer until tested.

Two different techniques and dilutions were used to prepare the leaves however the same Merck instrument was used to measure the nitrate levels:

- SAP was extracted from the first broccoli trial by firstly slicing five leaves into small pieces and squeezing them through a garlic press. One mL of SAP was then combined with 19 mL distilled water.
- SAP was extracted from the second broccoli and lettuce crops by slicing five leaves into small pieces and weighing out approximately 40 g combined with 40 mL de-ionised water and stomached for 30 seconds. The sample was then sealed and placed on an orbital shaker for 60 minutes at 4ºC. One mL was then pipetted into an eppendorf and frozen at -20ºC until later use. Samples were then thawed on the bench for approximately 30 minutes prior to nitrate analysis.

Nitrate was measured by dipping the test strip into solution for 2 seconds, removing it and any excess liquid vigorously shaken off. At the same time of dipping the test button on the spectrometer was pressed which counted down 60 seconds. With 5 seconds to go the test strip was inserted into the spectrometer. A reading between 5 and 250 g/mL was displayed and recorded. This last step was repeated and the results averaged before being multiplied by the dilution factor.

Plant growth assessments

In the first broccoli trial, entire fresh weight samples were taken at 2 stages of the growth cycle (at 4 and 8 weeks). Four plants were taken from each plot and weighed.

Head weight at harvest

Both broccoli and lettuce heads were harvested into large plastic crates, weighed by bench scales and the number of heads per plot recorded in the field. The minimum standard was 'marketable' heads except when the entire plots were harvested due to either bolting or animal damage. Plants that had been affected by pests, diseases, flowering or were too small were not harvested.

Irrigation patterns

Irrigation patterns were measured in the last broccoli and lettuce trials by placing one 5 L white ice-cream container in the middle of a plot and recording the amount of water collected from one hour of overhead irrigation. Volumes were measured by carefully tipping the water into a 250 mL measuring-cylinder and recording the data in the field. Irrigation volumes were recorded in all six blocks for broccoli and 4 blocks for lettuce. The data was not analysed by itself but as a covariate to yield.

Soil moisture

In the last lettuce trial, gravimetric soil moisture was calculated for each of the control plots in each block. Soil samples from the top 10 cm were taken with a hand spade at 3 different locations within a plot and placed on a pre-weighed aluminium tray and then dried in a 40ºC oven for a minimum of 48 hours. The dried soil samples were then re-weighed so that the soil moisture could be calculated.

Results

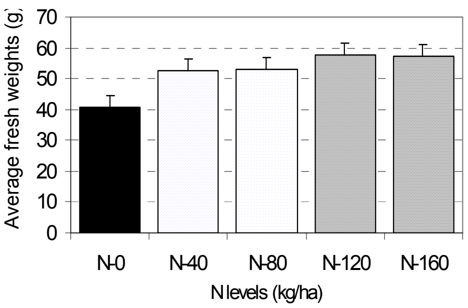
Broccoli 1

Plant growth assessments

The results from the first sampling at 4 weeks showed that there was no difference in fresh weights between treatments other than at the different nitrogen rates. The fresh weights increased with increasing nitrogen fertiliser (Figure 2.2). In contrast, the results from the second collection (8 weeks) showed that the treatments with SGWC had higher fresh weights than the FWC and the controls (no compost). There was no difference in average fresh weights between FWC and the controls (Figure 2.3).

Yield at harvest

At harvest, broccoli head-weight increased with increasing nitrogen fertiliser rate (Table 2.3). While there was not a significant difference in yield between the control and compost treatments, SGWC had a significantly higher marketable head size (11%) than FWC (Table 2.4).



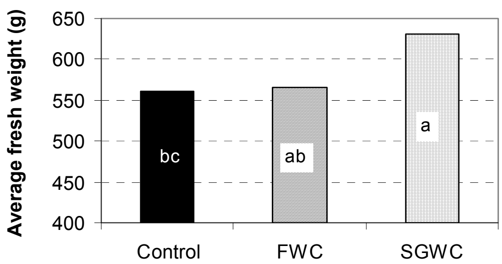


Figure 2.2. Average fresh weight of plants from first collection.

Figure 2.3. Average fresh weight of plants from second at 8 weeks after planting.

Table 2.3. Effect of N-fertiliser rate on the marketable head size of broccoli (Broccoli 1, harvest September 2001)

Marketable head size (g)	N-fertiliser rate (kg/ha)					lsd (P = 5%)
	0	40	80	120	160	
	145.7	180.1	199.9	217.4	234.2	9.1

Table 2.4. Effect of compost type on the marketable head size of broccoli (Broccoli I, harvest September 2001)

Marketable head size (g)	Compost type		
	Control	FWC	SGW
	199.1	184.7	204.4

lsd (5%) 19.0 - comparing means between compost and control;
15.5 - for comparing means between compost.

Plant analysis

In most cases, sap nitrate levels increased between the 80 and 160 kg/ha N-fertiliser rates (Table 2.5). All 160N treatments had significantly higher nitrate levels than both the lower applications (0N and 40N). At 160 kg/ha of N, there was a significant reduction (P = 0.05) in sap nitrate between the control and the higher compost rate (70 m^3/ha) for FWC indicating that nitrogen drawdown had occurred (Table 2.5). Both composts showed signs of nitrogen draw down as the rate of compost application increased (Table 2.6) but it was only statistically significant for FWC.

Table 2.5. Effect of N-fertiliser and compost on the nitrate levels of broccoli (Broccoli I, sampled August 2001)

Compost type and rate (m^3/ha)	*N-fertiliser rate (kg/ha)*					lsd (P 5%)
	0	*40*	*80*	*120*	*160*	
Control	*46.6*	*50.7*	*91.3*	*96.7*	*129.3*	
FWC35	*52.8*	*69.7*	*71.8*	*101.6*	*120.7*	
SGWC35	*39.7*	*56.9*	*65.8*	*100.2*	*106.8*	*35.1*
FWC70	*53.4*	*38.5*	*57.5*	*78.1*	*92.5*	
SGWC70	*27.3*	*45.1*	*71.6*	*84.1*	*126.8*	

Table 2.6. Effect of compost rate on the nitrate levels of broccoli (Broccoli I, sampled August 2001)

	Compost rate (m^3/ha)		
	Nil	*35*	*70*
Nitrate (mg/L)	*82.9*	*78.6*	*67.5*

lsd (5%) 12.7 - comparing means between rates of compost and control;
10.4 - comparing means between rates of compost only.

Compost analysis

SGWC had a lower C/N ratio, higher total and nitrate N 30, and a higher NDI than FWC (Table 2.7). FWC had a C:N of 35 which was higher than expected and was probably due to the inclusion of extra carbon material such as wood shavings. This may explain the evidence for nitrogen drawdown shown for FWC.

Table 2.7. Analysis of SGWC and FWC composts according to AS4454-1999 (Broccoli I)

Analysis	Units	SGWC	FWC
Moisture @ 40ºC	% w/w	40	44
Moisture @ 105ºC	% w/w	44	45
pH – 1:5 H_2O		7.9	7.7
Wetability	min	4	5
E.C.	dS/m	2.4	2.7
Na	mg/kg	1,900	2,400
Loss on Ignition (organic matter)	% w/w	38	75
C/N (Calc from Leco)		14	35
Total C	% w/w	18	35
N Drawdown 150 (NDI)		0.95	0.6
N	% w/w	1.3	1
NH_4-N	mg/L	< 5	< 5
NO_3-N	mg/L	30	< 5
P	mg/kg	1,800	1,300
K	mg/kg	9,000	10,000
S	mg/kg	940	920
Ca	mg/kg	21,000	7,100
Mg	mg/kg	4,700	2,300
Germination test	%	40	35
Toxicity test		46	55

Lettuce 1

This crop was severely affected by weeds and disease and was not harvested.

Broccoli 2

Head weight of broccoli increased with increasing rate of N fertilisation (P 5%; Table 2.8). Neither compost resulted in a significantly higher head weight compared to the control. However, SGWC resulted in a significantly higher head weight than FWC (P 5%; Table 2.9). There was no significant interaction between compost type or compost rate and rate of N.

Analysis of the composts showed SGWC to have higher levels of total and available N, total K and Ca compared to FWC (Table 2.10).

Table 2.8. Effect of rate of N fertilisation on head weight of broccoli 2 (October 2002)

Marketable head size (g)	N-fertiliser rate (kg/ha)					lsd (P = 5%)
	0	40	80	120	160	
	143.4	162.1	176.8	187.8	192.5	12.45

Table 2.9. Effect of compost type on head weight of broccoli 2 (October 2002)

Marketable head weight (g)	Type of compost		
	Control	FWC	SGW
	163.9	163.3	186.0

lsd (5%) 24.11 - comparing means between compost and control;
19.68 - comparing means between compost.

Table 2.10. Analysis of SGWC and FWC composts according to AS4454-1999 (Broccoli 2)

Analysis	Units	SGWC	FWC
Moisture @ 40ºC	% w/w	18	44
Moisture @ 105ºC	% w/w	20	45
pH-H_2O		6.9	7.5
Wetability	Min	11	3
E.C.	dS/m	4.6	2.7
Na	mg/kg	1,400	1,800
Loss on Ignition (organic matter)	% w/w	43	55
C/N (Calc from Leco)		16	24
Total C	% w/w	24	31
N Drawdown 150 (NDI)		0.4	0.2
N	% w/w	1.5	1.3
NH_4-N	mg/L	130	34
NO_3-N	mg/L	< 5	31
P	mg/kg	2,000	3,500
K	mg/kg	11,000	8,600
S	mg/kg	1,600	1,700
Ca	mg/kg	20,000	20,000
Mg	mg/kg	4,300	3,100
Germination test	%	95	95
Toxicity test		6	77

Lettuce 2

Due to animal damage, two blocks were excluded and the compost types were combined for statistical analysis. Overall, compost treatments significantly increased the yield of lettuce. Only at the compost rate of 70 m^3/ha was head size significantly affected by fertiliser rate (Table 2.11). At this rate of compost, highest yields were obtained at 60 kg N/ha.

Table 2.11. Effect of compost rate and N-fertiliser rate on the marketable head size of lettuce (Lettuce 2, harvest May 2003)

Marketable head size (g)		***Number of replicates***	***N-fertiliser rate (kg/ha)***				
			0	***30***	***60***	***90***	***120***
Compost rate (m^3/ha)	*Control*	*6*	*195*	*268*	*212*	*243*	*236*
	35	*12*	*308*	*271*	*258*	*258*	*344*
	70	*12*	*247*	*323*	*365*	*360*	*276*

lsd (5%) 152.4 - comparing means within control treatment;
13.0 - comparing means between control treatment and means in other treatments;
107.8 - comparing means within and between the 35 and 70 m^3/ha treatments.

Due to high variability, no consistent trends were observed with respect to the effect of compost type and rate on nitrate levels in lettuce leaves (Table 2.12). At 0 kg N/ha, there was some evidence that SGWC application resulted in reduced nitrate concentrations in the leaves.

Table 2.12. Effect of N-fertiliser and compost on the nitrate levels of lettuce leaves (Lettuce II, sampled May 2003)

Compost type and rate (m^3/ha)	**N-Fertiliser rate (kg/ha)**					**lsd (P 5%)**
	0	**30**	**60**	**90**	**120**	
Control	700.9	433.2	582.8	617.1	630.5	
FWC35	377.3	499.2	757.6	827.0	617.4	
SGWC35	299.3	427.8	625.9	611.7	798.3	386.6
FWC70	805.5	587.0	725.7	697.4	750.6	
SGWC70	99.9	545.1	551.8	264.0	807.6	

Analysis of each compost showed that SGWC had a higher NDI and available N content than FWC (Table 2.13). In the SGWC, the C:N ratio, total and available N contents and NDI are close to the recommended specifications for the use of compost in vegetable production.

Table 2.13. Analysis of SGWC and FWC composts according to AS4454-1999 (Lettuce II)

Analysis	Units	SGWC	FWC
Moisture @ 40ºC	% w/w	33	33
Moisture @ 105ºC	% w/w	34	37
pH-H_2O		8.2	7.1
Wetability	min	3	9
E.C.	dS/m	4.5	3.1
Na	mg/kg	1,900	2,000
Loss on Ignition (organic matter)	% w/w	55	39
C/N (Calc from Leco)		16	17
Total C	% w/w	23	27
N Drawdown 150 (NDI)		0.7	0.3
N	% w/w	1.4	1.6
NH_4-N	mg/L	86	35
NO_3-N	mg/L	5.9	8.7
P	mg/kg	2,000	7,000
K	mg/kg	8,800	8,400
S	mg/kg	1,600	2,600
Ca	mg/kg	18,000	20,000
Mg	mg/kg	3,300	3,700
Germination test	%	100	100
Toxicity test		28	45

Soil analysis

Both composts resulted in increases in soil pH over time (Figure 2.4). It is typically observed with compost application that soils tend to approach a neutral pH after repeated compost application.

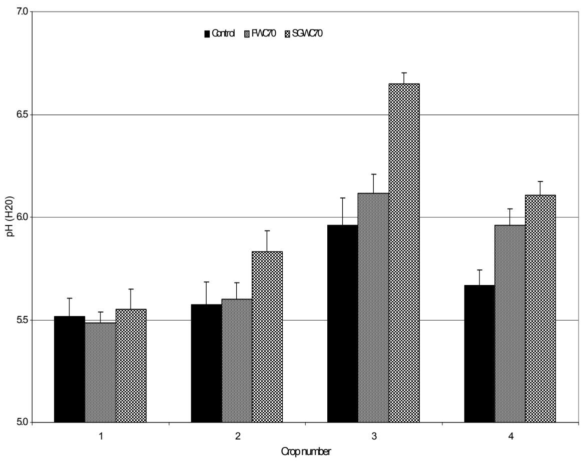


Figure 2.4. Effect of four applications of compost on soil pH. Means of 12 samples with s.e. bars.

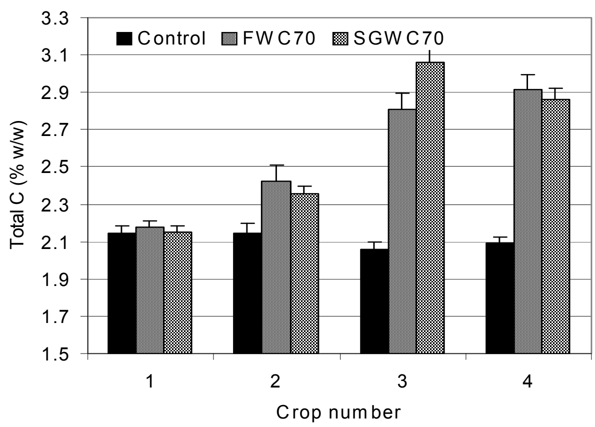


Figure 2.5. Effect of four applications of compost on soil C. Means of 12 samples with s.e. bars.

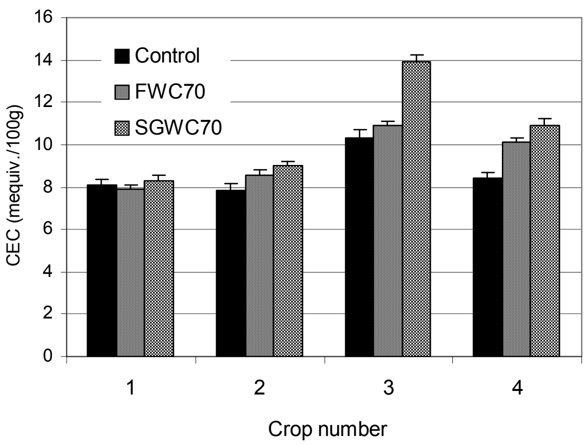


Figure 2.6. Effect of four applications of compost on Olsen P. Means of 12 samples with s.e. bars.

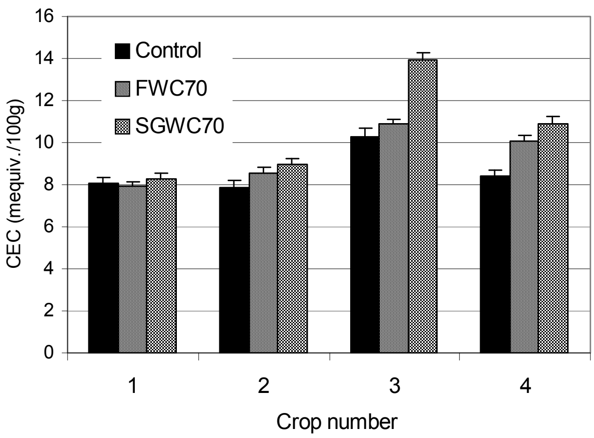


Figure 2.7. Effect of four applications of compost compost on cation exchange capacity. Means of 12 samples with s.e. bars.

Both composts also resulted in increases in CEC, which is normally associated with increasing soil organic C as a result of repeated compost application (Figures 2.5 and 2.7). Small increases in soil nutrient levels were also observed (e.g. Olsen P, Figure 2.6). A more detailed table of soil analytical results in shown in Table 2.14.

Table 2.14. Soil analytical data for the N-replacement trial. Results shown are the means and SD's of 12 samples after each harvest. Samples were collected from the compost treatments shown at low, mid and high rates of N application

Analyte	Units	Control								FWC70							
		1st crop		2nd crop		3rd crop		4th crop		1st crop		2nd crop		3rd crop		4th crop	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
pH	1:5 H_2O	5.58	0.3	5.58	0.37	5.96	0.47	5.67	0.26	5.48	0.19	5.6	0.27	6.12	0.32	5.96	0.28
EC	dS/m	0.14	0.3	0.1	0.01	0.23	0.05	0.18	0.03	0.14	0.02	0.12	0.04	0.2	0.05	0.16	0.05
TSS	% w/w	0.03	0.01	0.03	0	0.07	0.02	0.06	0.01	0.05	0.01	0.04	0.01	0.06	0.01	0.05	0.01
Total C	% w/w	2.14	0.15	2.14	0.2	2.06	0.14	2.09	0.12	2.18	0.13	2.43	0.29	2.81	0.31	2.92	0.28
NH_4-N	mg/L					2.25	2.42	2.33	1.37					2.67	2.53	2.67	0.78
NO_3-N	mg/L					39	32.41	37.25	18.85					16.75	21.34	17.42	16.54
Total N	mg/kg	0.14	0.01	0.14	0.01	0.15	0.01	0.15	0.01	0.15	0.01	0.17	0.02	0.19	0.02	0.22	0.02
Ols P	mg/kg	30.33	6.37	30.33	6.17	64.58	18.41	32.42	6.08	32.42	6.14	40.83	7.95	70.08	14.85	48.25	8.86
Est K	mg/kg	88.17	16.38	88.17	17.71	192.5	47.31	110.17	12.43	129.17	17.3	125.83	26.35	257.5	39.57	201.67	30.10
CPC S	mg/kg	36.42	4.89	36.42	7.34	66.92	19.37	51.42	10.39	31	4.2	49.58	20.36	51.17	18.56	45.67	14.53
Ex Ca	meq/100 g	6.2	0.81	6.2	0.9	8.33	1.12	6.53	0.74	6.07	0.61	6.48	0.59	8.48	0.64	7.41	0.52
Ex Mg	meq/100 g	1.26	0.21	1.26	0.21	1.28	0.17	1.34	0.18	1.26	0.13	1.5	0.19	1.55	0.2	1.77	0.17
Ex Na	meq/100 g	0.13	0.02	0.13	0.03	0.16	0.02	0.22	0.03	0.19	0.02	0.21	0.05	0.22	0.04	0.36	0.05
Ex K	meq/100 g	0.23	0.04	0.23	0.04	0.49	0.12	0.28	0.03	0.33	0.04	0.32	0.07	0.66	0.1	0.52	0.07
CEC	meq/100 g	7.86	0.98	7.86	1.13	10.31	1.3	8.4	0.89	7.91	0.72	8.58	0.8	10.89	0.71	10.1	0.80
Ca:Mg		5	0.46	5	0.48	6.55	0.65	4.93	0.35	4.88	0.37	4.39	0.38	5.59	0.7	4.24	0.26
Ca	%	79.83	1.17	79.83	1.53	81.5	0.9	78.42	1.16	77.83	1.11	76.42	1.62	78.08	1.88	74.33	1.30
Mg	%	16.5	1.3	16.5	1.31	13	0.95	16.33	0.89	16.5	1	17.92	1.16	14.58	1.44	18	0.85
Na	%	2	0.51	2	0	1.92	0.29	3.17	0.39	2.75	0.45	2.75	0.62	2.25	0.45	4	0.60
K	%	3.33	0.43	3.33	0.49	5.33	1.07	3.83	0.39	4.67	0.65	4.08	0.79	6.5	1.17	5.58	0.67

Table 2.14 continued …

Analyte	Units	SGWC70							
		1st crop		2nd crop		3rd crop		4th crop	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
pH	1:5 H_2O	5.55	0.34	5.83	0.34	6.65	0.18	6.11	0.22
EC	dS/m	0.15	0.01	0.12	0.03	0.26	0.09	0.2	0.04
TSS	% w/w	0.05	0	0.04	0.01	0.08	0.03	0.06	0.01
Total C	% w/w	2.15	0.11	2.36	0.13	3.06	0.31	2.86	0.22
NH_4-N	Mg/L					2.08	0.29	2.25	0.62
NO_3-N	mg/L					14.58	13.17	33.58	17.7
Total N	mg/kg	0.15	0.01	0.17	0.01	0.22	0.02	0.21	0.02
Olsen P	mg/kg	30.5	8.2	36.83	8.36	81.5	12.24	45.5	8.76
Est K	mg/kg	130	18.59	140.83	26.1	425	53.85	230	40.9
CPC S	mg/kg	33.58	8.73	35.83	14.6	63.5	22.5	46.17	9.75
Ex Ca	meq/100 g	6.35	0.77	6.89	0.69	10.54	0.84	8.15	0.74
Ex Mg	meq/100 g	1.39	0.16	1.53	0.16	1.95	0.19	1.82	0.17
Ex Na	meq/100 g	0.19	0.02	0.21	0.04	0.23	0.04	0.37	0.04
Ex K	meq/100 g	0.33	0.05	0.36	0.07	1.09	0.14	0.58	0.1
CEC	meq/100 g	8.3	0.92	8.99	0.77	13.92	1.16	10.91	1.08
Ca:Mg		4.6	0.32	4.57	0.32	5.48	0.48	4.54	0.17
Ca	%	77.17	1.47	77.17	1.34	76.83	1.47	75.17	1.11
Mg	%	17.25	0.87	17.42	1	14.33	0.98	17.17	0.58
Na	%	2.75	0.45	2.67	0.49	2	0	3.75	0.45
K	%	4.42	0.67	4.33	0.78	8.25	1.14	5.67	0.98

Conclusions

These results have shown modest improvements in soil conditions following the application of composted soil amendments to heavy soils at DPI Knoxfield. These improvements did not result in consistent increases in crop productivity because crop growth was often compromised by either compost quality, weeds and diseases and bird damage. As a result of these factors, the capacity to measure the contributions of the composted amendments to crop N nutrition was compromised. Given that the quality of the compost did not live up to expectations in most cases, it would have been unlikely that improvements in N nutrition would have been seen over only four applications of compost.

The work highlights again the paramount importance of compost quality to enable their beneficial use in vegetable production. Whilst improvements to quality still need to be made, the soft green waste (SGW) compost in particular, could be a useful soil conditioner for vegetable production. This product was usually free from contamination, despite the fact that the feedstock for it (mainly grass clippings) is collected in mobile garbage bins (MGB's) from households. Many compost producers are reluctant to accept this material for fear of high levels of contamination.

SGWC consistently out-performed the food waste compost (FWC) in the trials, and though improvements to quality and consistency still need to be made, the analysis of the SGWC was often close to desired specifications. This is a promising finding given that green waste is likely to remain the most important component of organic waste feedstock for composting in the metropolitan areas around Australia. However, distinction needs to made about the different sources of green waste. Other types of green waste are more woody in nature and need to be composted for longer periods or need to be more finely screened (Western Australian and Californian experience suggests 10 to 12 mm screens (Paulin 2001; Paulin *et al.* 2002)) to make a product suited for vegetable production.

In these trials, the food waste compost (FWC) was more likely to have caused N-drawdown more often than the SGW compost. Food wastes are relatively high in moisture content and must be blended with drier bulking agent prior to composting. This has often meant that the FW compost had a relatively high C:N ratio and a propensity to drawdown N. With the proper attention to process management, these composts can also be manufactured into high quality composts.

The FWC highlights an important barrier that must be overcome with respect to compost production, viz the tension between the objectives of efficiently managing wastes and the quality requirement of the end product. These two objectives are often in conflict because the demands of composting many waste streams, especially those that are high in nutrients or moisture may compromise the quality of the end product for a particular purpose. However, in this case, the compost may be highly suitable for other applications. Thus a better understanding of the relationship between sources of waste streams, compost processes and fit for purpose applications is needed.

SECTION 3 – SYSTEMS TRIALS – WESTERN AUSTRALIA

Introduction

Continuous crop rotations, intensive management including extensive use of rotary cultivation and coarse sand texture of the Swan Coastal Plain explain the universally low soil carbon levels and poor soil fertility.

The nature of these soils (Coarse Sands more correctly), the Mediterranean climate with associate warm to hot summer temperatures and current management practices require relatively large amounts of fertiliser and irrigation. The legacy of these practices can be very high levels of nitrates and in some situations, phosphorus in the groundwater. The impacts of phosphorus are usually minimised by the ability of the preferred coloured sands to bind phosphorus. This phosphorus sorbtion is associated with the presence of Aluminium, Iron Sesquioxide content of these soils that is also responsible for their colour. However, more importantly, these potential impacts and particularly those of nitrogen on groundwater quality have been masked by urbanisation that continues to be associated with the rapid growth of Perth. Typically, vegetable production areas have been urbanised every 10 to 20 years.

The System trial site was established to investigate management practices that would maximise the potential benefits of using compost and the use of clay was selected because it would improve the soils physical character and potentially improve soil organic matter accumulation.

The reuse of significant volumes of reclaimed water (treated water from metropolitan sewage treatment) is a major component of water conservation strategies around Australia and because of their location, vegetable production is usually well placed to utilise this resource. This already occurs on the Virginia Plains North of Adelaide and in Perth, recharging aquifers currently used for vegetable production is being considered. A major advantage of this process will be savings in infrastructural costs necessary to deliver this water to individual farms and to minimise further treatment requirements. Ground water recharge and subsequent extraction for food production is currently practiced in Israel and California.

The investment necessary in recharging groundwater will necessitate a change to urbanisation practices and is already promoting the establishment of permanent agricultural/rural precincts. As a consequence, the long term management of ground water will become a greater issue and the development of practices that conserve and increase soil organic matter will add to the potential for managing these risks by further increasing the potential to better manage irrigation and fertiliser.

Materials and methods

The site was established to compare three independently irrigated treatments. Plots, 18 m by 6 m wide, were replicated four times. With four beds per plot, sampling and harvesting was carried our within the inner two beds bed. The site was fumigated with Metham Soil Fumigant (Metham 423 g/L) prior to commencing the trial program.

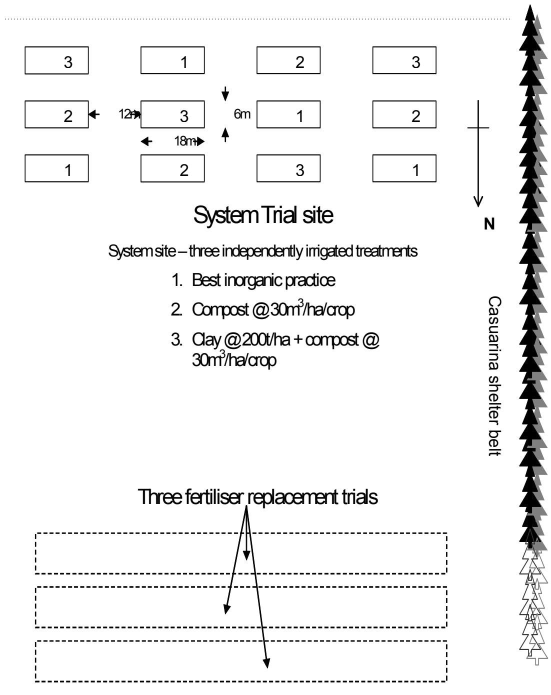
The site was comprehensively soil sampled prior to the application of amendments when twelve samples per plot at three depths were collected using standard sand augers and the averaged results are provided in Table 3.1. All samples were analysed at the Government Chemistry laboratories in Perth. Top 15 cm of soil in individual treatment replicates were subsequently sampled immediately after establishment of the first, third and final trial (S-1, S-3 and S-5). With the final sampling, the 15 to 30 cm depth was also included.

Table 3.1. Soil analysis prior to trial establishment

Analyt	Sample depth (cm)		
	0-15	15-30	30-45
Ec	1.67		
pH	6.99		
P (PRI)*	1.56	1.52	1.64
Total N	0.02	0.02	0.01
P Total	31.42	32.58	28.00
P ($HC0_3$)	3.17		
K ($HC0_3$)	10.50	10.00	< 10
Ex Ca	1.35		
Ex Mg	0.16		
Ex Na	0.06		
Ex K	0.02		

* Phosphorus retention index.

Irrigation was established with traditional 'butterfly' sprinklers because their large droplet size and high precipitation rate provide the best possible distribution uniformity. Eight sprinklers per plot were installed around the perimeter of each plot.



Automatic irrigation control was provided to each treatment using Electronic tensiometers. A set of three tensiometers were installed at 15, 30 and 45 cm depth in each treatment and logged at 15 min intervals to monitor soil moisture changes and guide the overall irrigation management program. The irrigation was managed in response to pre set moisture levels at two depths in order to allow both moisture level and watering depth to be managed. Although varied, these monitoring depths were normally set at 10 to 15 cm and 25 to 30 cm.

TDR's (Time Domain Refractometers) were also installed to one replicate of each treatment to provide additional soil moisture monitoring.

In conjunction with the tensiometers, lysimeters similar to those installed at the Fertiliser replacement trial site and rain gauges were installed so that both irrigation and fertiliser utilisation could be monitored.

The lysimeters were pumped out weekly to determine leaching losses and sub samples were frozen for later nutrient analysis.

Treatments

The three treatments selected at the system site were:

- Soil amended with 200 t/ha clay prior to commencement of the trial program to raise the clay content to 5%. In addition to the clay, compost at 30 m^3/ha was applied prior to the establishment of each crop.
- Compost at 30 m^3/ha applied prior to each crop; and
- Standard inorganic management.

Based on research with claying agricultural soils (Carter 1998), 200 t/ha of clay was applied and incorporated to a depth of 30 cm in order to achieve a 5% clay content.

Clay was obtained from a local pit operated by Alcoa Australia and was spread and incorporated on 8 August 2002. The clay used was typical of the transitional clays found on the coastal plain and they have a reasonable cation exchange capacity due to a significant expanding clay content of mainly Smectite (Table 3.2).

Table 3.2. Analysis of clay used at System trial site

Ec (1:5)	pH ($CaCl_2$)	% Sand	% Silt	% Clay	CEC (NH_4Cl) me%
61	5.8	29	12	59	36a

Crop management

The basic management practices for trials at the Medina research Station involve typically three rotary cultivations per trial.

Fertiliser

Phosphorus requirements as Double Super together with a standard trace element mix were applied in a single application prior to establishing each trial. Rates of phosphorus were bases on soil analysis and compost contributions.

The standard trace element mix provides the following, expressed as kg/ha:

Magnesium Sulphate	56.0	Manganese Sulphate	50.4
Borax	33.6	Iron Sulphate	33.6
Copper Sulphate	33.6	Zinc Sulphate	28.0
Sodium Molybdate	2.24		

Nitrogen, as Urea, potassium usually as Potassium Nitrate and magnesium as Magnesium Sulphate applied at weekly intervals using either tractor mounted boom spray or occasionally by hand using watering cans. They were combined to achieve required weekly application rates and applied in 1000 L/ha of water to minimise the possibility of foliage damage. The weekly rates for the first four crops (S-1 to S-4) were adjusted in accordance with a schedule, outlined in Table 3.3 and based on crop development and growing cycle. The final crop of lettuce (S-5) received a modified program that had been developed in conjunction with Lettuce industry development project VG99004 (Phillips 2003). This program was developed from work to replace grower use of raw poultry manure that a number of lettuce growers are still heavily dependent on. Essentially the program applies nitrogen and potassium twice weekly, using foliar spray, during the initial two weeks of crop establishment which is the period when they are vulnerable to nutrient leaching from rainfall and excessive irrigation.

Table 3.3. Distribution of fertiliser application over life of five crops grown at the system site

Week N°.	Weekly fertiliser application as % of total				
	Carrot S-1	Lettuce S-2	Broccoli S-3	Carrot S-4	Lettuce S-5
Sowing/planting	1.25	0.0	0.0	0.0	5.0
2	2.5	5.0	5.0	2.0	8.0
3	3.0	8.0	8.0	2.0	27.0
4	4.0	10.0	10.0	3.0	20.0
5	5.0	10.0	10.0	4.0	20.0
6	7.0	12.0	12.0	6.0	20.0
7	8.0	12.0	12.0	7.0	
8	9.0	12.0	12.0	8.0	
9	9.5	10.0	10.0	10.0	
10	10.5	8.0	8.0	12.0	
11	11.5	4.5	4.5	14.0	
12	11.0	0.0	0.0	13.0	
13	9.25	0.0	0.0	11.0	
14	6.0			8.0	
15	2.5			0.0	
16	0.0			0.0	

Irrigation

During the initial crop establishment period, normally the first week, the irrigation was applied three times each day to supply 100% of evaporation measured in a standard pan (Epan).

Automatic irrigation was then used. During the weeks 2 and 3, the 15 cm tensiometers at a depth of 10 cm and irrigation was triggered twice each day when soil moisture tension reached -5 centibars and the volume was applied to a calculated 50% of the Epan. A further watering was triggered when the 30 cm tensiometer reached -8 centibars.

From week 4 to harvest, the upper tensiometer was reinstalled to 15 cm depth and the irrigation triggering managed as per weeks 2 and three.

Pest and disease management

Insecticide, fungicide and herbicides application followed standard practices at the Medina Research Station and targeted the problems listed in Table 3.4.

Nematodes were a significant undetected problem prior to trial establishment and while the pre trial fumigation had some effect, they had a major impact on the first carrot crop. The decision was therefore made to use the soil fumigant Telone C-35 (345 g/L Chlorpicrin plus 615 g/L 1, 3–Dichloropropene) prior to the second crop.

Table 3.4. Pest and disease concerns and their treatment

Crop	Weed, Pest/disease	Treatment®
S-1 and S-4 Carrot Summer	Weed control: At planting. Disease control: Nil Pests: Nil	Herbicide: 1.1 L/ha Afalon, (450 g/L *Linuron*) plus 2.0 L/ha Triflualin
S-2 and S-5 Lettuce Autumn	Weed control: At planting. Disease: Sclerotinia (*Sclerotinia sclerotiorum*) Pests: Nil	Herbicide: 3 L/ha Kerb (500 g/L *Propyzamide*) Fungicides: 500 g/L Sumisclex (500 g/L *Procymidone*) 2 L/ha Bavistin (500 g/L *Carbendazim*) 1.6 kg/ha Mancozeb (750 g/kg *Mancozeb*) Acrobat (600 g/kg *Mancozeb* + 90 g/kg *Dimethorph*)
S-3 Brocolli Winter - spring	Weed control: At planting. Disease: Nil Pests: Diamondback moth *(Plutella xylostella*)	Herbicide: 6 kg/ha (Dacthal (900 g/kg *Chlothal Dimethyl*) Fungicide: Sumisclex (500 g/L *Procymidone*) Insecticide: 500 g/ha Xentari, *Bacillus Thuringiensis* 500 g/L

Harvesting

The cropping sequence together with planting and harvesting times is provided in Table 3.5. Crop performance was measured as total and marketable yields from either a single harvest or over a sequence of harvests and the results presented as tonnes per ha (t/ha).

Table 3.5. Crop sequence at the System trial site

Crop	Planted	Harvested
S-1 Carrot	23 October 2002	20 February 2003
S-2 Lettuce	8 April 2003	3 June 2003
S-3 Broccoli	7 August 2003	20 October 2003
S-4 Carrot	17 November 2003	10 March 2004
S-5 Lettuce	1 April 2004	20-25 May 2004

System trial, lettuce harvesting, note *Casuarina cunninghamians* shelter.

Results and discussions

Information is presented for each crop covering fertiliser and pest management, compost quality, crop performance as total and marketable yield, plant and for selected crops, soil nutrient analysis and irrigation. Nitrogen leaching was only assessed for the final two crops (S-4 and 5). Brief discussions of the results are also presented with each trial.

Carrots, crop S-1

The initial carrot crop, variety Stefano was sown on the 23 October 2002 and was harvested on the 20 February 2003.

Growing conditions

Typical summer growing conditions were experienced with warm to hot weather and very little rainfall. These conditions and the application of irrigation are summarised as weekly averages in Figure 3.1A and 3.1B.

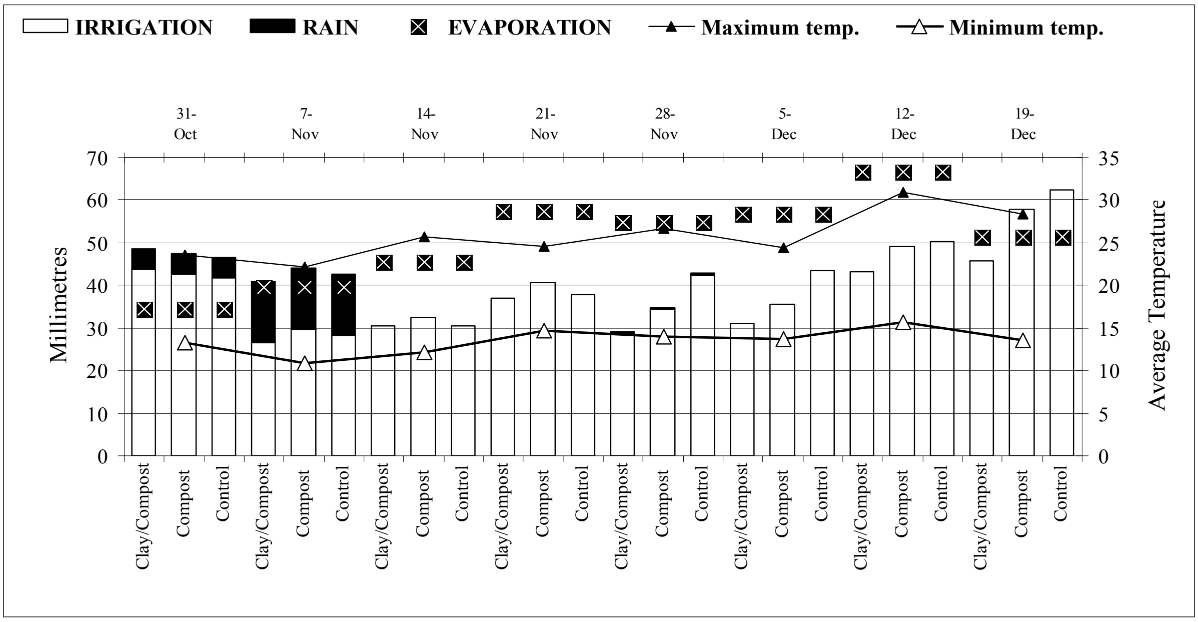


Figure 3.1A. **Average weekly weather conditions and irrigation application for the late October to late December period of the initial carrot crop at the system site.**

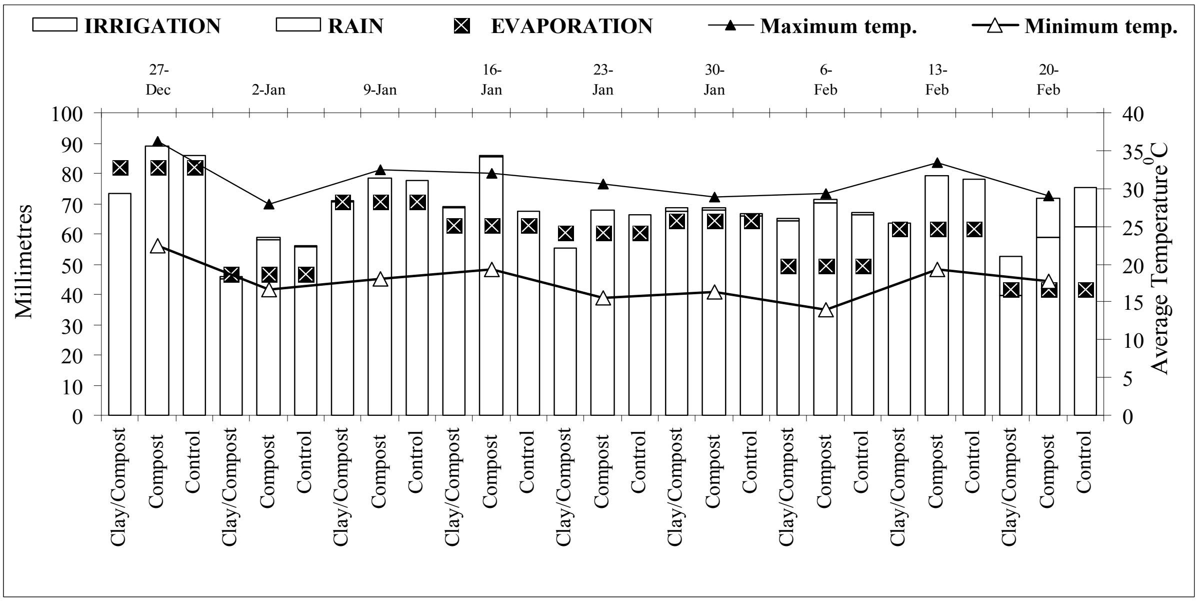


Figure 3.1B. **Average weekly weather conditions and irrigation application for the late December to February period of the initial carrot crop at the system site.**

Fertiliser program

In addition to the fertiliser program outlined in Table 3.6, 320 kg/ha of the standard trace element mix was applied. This was broadcast and incorporated with a rotary cultivator to 15 to 20 cm depth prior to crop establishment in conjunction with the application of Double Superphosphate.

Table 3.6. Fertiliser application to Carrot crop S-1 at the System site

Week N°.	kg/ha				
	P	N	K	Mg	Borax
Compost + clay	320.0	299.9	234.8	Nil	15.1
Compost	110.0	299.9	234.8	Nil	15.1
Control	180.0	299.9	13.4	22.9	0.9

The rates of phosphorus applied reflect the anticipated influence of applying 200 t/ha of clay on its absorption by the soil and the contribution from compost.

Pest, disease and weed management

The crop was severely affected by nematodes (*Meloidogyne javanica*) that disfigured the carrots and resulted in marketable yields well below commercial expectations.

Apart from nematodes, there were no pest and disease problems and the standard pre-emergent herbicide (Afalon® plus Triufluralin®, Table 3.5) was applied following sowing the crop on 23 October 2002.

Compost quality

The compost quality used for the initial carrot trial was marginal (Table 3.7) with most aspects considered to be important, being outside of the specifications that have been developed. In particular there are indications that the compost was immature because the soluble nitrogen was dominated by ammonium nitrogen (NO_3/NH_4 ratio less than 0.10).

Table 3.7. Compost applied to Carrot crop S-1 at the system site

Analyt	Carbon Nitrogen ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	NH_4 + NO_3	NO_3/NH_4 ratio
Critical value	*< 20*	*> 0.5*	*> 60*	*> 1.0*	*> 100*	*> 0.14*
Compost S-1	25	0.37	100	1.2	78	< 0.10

See Appendix 3.1 (Compost 10A) for more detailed analysis of all composts used at the system trial site.

Harvest, crop S-1

The carrots were hand harvested on the 20 February, washed and assessed for total and marketable yield (Grade A,B), and the results are summarised in Table 3.8. Categories of rejects were assessed and apart from nematode damage that caused enlarged lenticels, the main defect was forking. While the nematodes possibly added to this problem, it is usually attributed to Cavity Spot, a complex disorder that has a number of causes that include disease (*Pythium* spp.) and soil quality issues (Galati 1996).

Total yield was not affected by treatment, however marketable yield was significantly reduced ($P = 0.01$) by the application clay.

Table 3.8. Total and marketable carrot yields (t/ha) from the first crop at the System trial site at the Medina Research Station

Treatment	Harvested crop (t/ha)		
	Total	Marketable	% Forked
Clay plus compost	76.26	17.2	34.4
Compost	73.01	30.5	9.9
Control	77.54	34.4	12.5
lsd (1%)	*ns*	*8.6*	*16.5*

Soil analysis

The trial site was sampled immediately after planting and the results are provided in Table 3.9.

Table 3.9. Soil analysis (top 15 cm) at planting of first crop on the System trial site (Treatment Means)

Analyte	Compost + clay	Compost	Control	lsd 5%
Ec (1:5 H_20)	12.25	7.25	5.75	1.63
pH ($CaCl_2$)	6.80	6.82	6.55	ns
Org C %WB	na	na	na	na
N Total %db	0.032	0.024	0.016	0.006
NO_3 + NH_4 mg/kg	2.0	1.0	1.0	0.82
P Total mg/kg	165	131	84	50
P (HCO_3) mg/kg	102	50	44	23
PRI %	-1.18	-0.75	-1.15	0.63
K (HCO_3) mg/kg	54	43	9	21

The addition of clay caused a slight increase in electrical conductivity. Compost and clay increased soil total nitrogen and plant available N present as nitrate. The additional Phosphorus fertiliser added to the clay treated plots increased total and bicarbonate extractable phosphorus to levels know to achieve maximum yields in carrots. Levels in the compost and control plots were marginal and an extra 50 kg/ha of phosphorus as phosphoric acid was applied four weeks into the crop. The PRI of all treatments indicated that the soil was saturated with phosphorus and P was freely available for plant growth.

Foliar analysis

The results of the youngest fully matured leaves, collected at harvest and analysed by Government Chemistry Centre in Perth, are presented in Table 3.10.

There were few treatment differences in the carrot foliage nutrient levels and apart from low copper and particularly manganese levels, they are generally within the recommended range for the nutrients analysed.

Table 3.10. Analysis of youngest fully matured carrot leaf at harvest

Analyt	Compost plus clay	Compost	Control	lsd (5%)	Adequate
% dm					
N	3.18	3.15	3.05	ns	2.0-3.5
P	0.36	0.29	0.30	0.04	0.2-0.35
K	3.35	4.10	3.86	0.52	2.5-4.5
Ca	2.34	2.26	2.32	ns	1.4-3.0
Mg	0.48	0.34	0.36	0.06	0.3-0.55
S	0.31	0.30	0.30	ns	0.32-0.63
Na	0.81	0.51	0.58	0.20	0.66-4.5
mg/kg					
Cu	4.67	4.25	2.98	0.78	10-25
Mn	24.50	21.20	23.50	ns	130-350
Zn	22.50	17.00	17.50	4.80	20-50
B	50.50	53.20	56.00	2.20	30-80
Fe	235.00	198.00	210.00	ns	120-350

* lsd - Least significant difference P = 0.05.
** Reuter, D.J. and Robinson, J.B. Plant analysis second edition CSIRO Publishing 1997.

Irrigation

Irrigation applied in response to soil moisture levels was recorded by flow meters and are provided in Table 3.11 along with averaged leachate information. The leachate is expressed as a percentage of the quantity of irrigation plus rainfall that was collected in the rain gauges that were located adjacent to each lysimeter.

Table 3.11. Irrigation applied to the carrot crop S-1 and the leachate collected at the System site

Treatment	Applied irrigation		Leachate collected	
	Total (kL/ha)	% Saving	% of application	% Reduction
Compost + clay	11,296	11.4	10.1	49.5
Compost	12,289	3.7	23.4	-16.8
Control	12,754	0.0	20.1	0.0

Discussion

The relatively poor quality compost had no significant effect on total carrot yield, Clay treatment significantly reduced marketable yield (P = 1%) and is likely to have been the result of experimental design and nematode distribution. A survey of nematode damage indicated that it was most severe along the northern boundary of the trial site and of the four plots involved, two were clay treated. Of the 24 sub-samples harvested from these plots, seven had no marketable carrots. Six of these were from two of the four Clay/compost treated plots.

In terms of irrigation demanded, the results indicated that the clay plots received over 10% less irrigation and percentage leachate collected was almost 50% less than the control plots.

The impact of compost alone was much less and could not be considered different from the control treatment.

Lettuce, crop S-2

Although the continuing presence of nematodes was not a problem for lettuce, it was decided to re-fumigate the site prior to establishing the second crop at the System site. The lettuce, variety Magnum, was planted on the 8 April 2003.

Growing conditions

Significant rainfall was experienced during the 55 day lettuce crop and irrigation was reduced due to the combination of rain and reduced evaporation. These conditions and the application of irrigation are summarised as weekly averages in Figure 3.2.

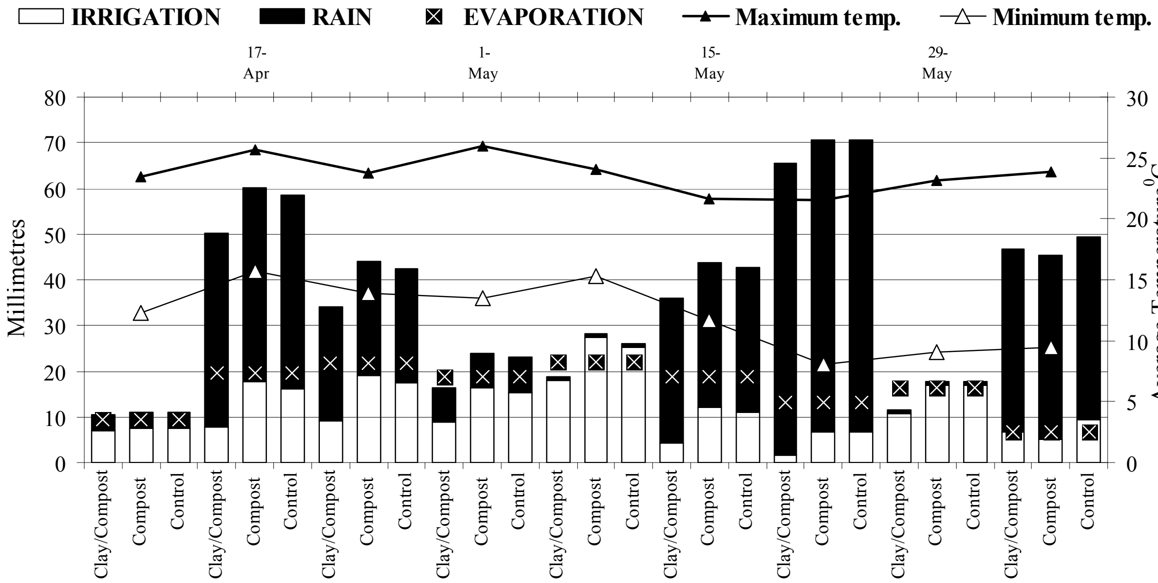


Figure 3.2. Average weekly weather conditions and irrigation application for the initial lettuce crop (S-2) at the system site.

Fertiliser management

In addition to the fertiliser program outlined in Table 3.12, 320 kg/ha of the standard trace element mix was applied. This was broadcast and incorporated with a rotary cultivator to 15 to 20 cm depth prior to crop establishment in conjunction with the application of Double Superphosphate.

Table 3.12. Fertiliser application to first lettuce crop (S-2) at the System site

Week N^{o}.	kg/ha				
	P	N	K	Mg	Borax
Compost + clay	332.0	349.60	340.00	Nil	15.10
Compost	253.0	349.60	340.00	Nil	15.10
Control	290.0	349.60	400.00	25.00	15.38

Pest, disease and weed management

There were no pest or disease problems encountered during the life of the crop. The herbicide Kerb® was applied after transplanting the seedlings on the 9 April 2003.

Compost quality

The compost quality in the lettuce trial (Table 3.13) was an improvement over that used in the previous trial, there were still indications that the compost was immature because of the low Nitrogen Draw Down and high ammonium nitrogen levels resulting in the low NO_3/NH_4 ratio value. Toxicity was also high.

Table 3.13. Compost applied to the first lettuce crop (S-2) at the system site

Analyt	Carbon Nitrogen Ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	NH_4 + NO_3	NO_3/NH_4 ratio
Critical value	*< 20*	*> 0.5*	*> 60*	*> 1.0*	*> 100*	*> 0.14*
Compost S-2	18	0.36	< 5.0	1.7	300	< 0.10

See Appendix 3.1 (Compost 11A) for more detailed analysis of all composts used at the system trial site.

Harvest, crop S-2

A successful crop of iceberg lettuce was grown following the re-fumigation of the site. Harvested weights are presented in t/ha Table 3.14. Total weights represented the above ground plant and all outer leaves were removed, as in the preparation of commercial export lettuce, to give the head weight.

Table 3.14. Total and marketable lettuce yields (t/ha) from the second crop (S-2) at the System trial site

Treatment	Total	Head	% Head wt
Compost + clay	82.58	45.81	55.5
Compost	75.61	45.77	60.6
Control	71.84	41.70	58.1
lsd (P 5%)	*2.01*	*1.306*	*1.2*

Lettuce above ground plant weight and marketable head weights were significantly increased (P = 0.05) by the application of compost. When compared to the compost alone treatment the addition of clay reduced the percentage marketable head weight, but increased total weight of lettuce.

Foliar analysis

The results from nutrient analysis of outer wrapper leaves that were collected at harvest and analysed by Government Chemistry Centre in Perth, are presented in Table 3.15.

Nutrient values tended to be higher in lettuce grown with compost plus clay, however with the exception of zinc; the minor nutrients and calcium values were below the recommended range.

Table 3.15. Analysis of outer wrapper leaves collected at harvest of lettuce from the second trial at the System site

Analyt	Compost plus clay	Compost	Control	lsd* (5%)	Adequate**
% db					
N	3.68	3.21	3.44	0.39	3.3-4.0
P	0.70	0.59	0.62	0.05	0.4-0.6
K	6.04	6.89	6.07	0.55	5.0-8.0
Ca	1.00	1.08	0.99	ns	1.4-2.0
Mg	0.38	0.30	0.32	0.02	0.3-0.7
S	0.23	0.25	0.26	ns	0.3-0.32
Na	0.813	0.66	0.73	0.07	0.5-1.0
mg/kg					
Cu	6.3	6.30	5.3	ns	10- 18
Zn	44.2	30.0	33.5	ns	25- 55
Mn	37.0	29.8	34.5	ns	50-500
B	28.5	28.3	27.5	ns	50-300

* lsd - Least significant difference P = 0.05.
** Reuter, D.J. and Robinson, J.B. Plant analysis second edition CSIRO Publishing 1997.

Irrigation

Irrigation applied in response to soil moisture levels are provided in Table 3.16 for each treatment along with the percentage irrigation plus rainfall that was collected in the lysimeters under each of the four treatment replicates.

Table 3.16. Irrigation applied to the lettuce crop S-2 and the leachate collected at the System site

Treatment	Applied irrigation		Leachate collected	
	Total (kL/ha)	% Saving	% of application	% Reduction
Compost + clay	10,430	40.1	47.5	12.8
Compost	15,880	8.8	55.0	-1.0
Control	17,410	0.0	54.4	0.0

Large savings (40%) in irrigation were provided by the compost plus clay but saving associated with compost alone were small. The high percentage of the rain gauge readings collected in the lysimeters compared to the previous crop indicate the season and the accompanying lower evaporation combined with higher rainfall.

Discussion

The lettuce produced in this second System trial were very high quality (Figure 3.3) and both compost treatments produced significantly higher yields (P = 0.05) of marketable heads. There were also differences due to the addition of clay and while there is a suggested increase in above ground plant weight, the clay significantly reduced the head weight compared to the compost alone treatment.

It is possible that the addition of clay had delayed lettuce development and that the marketable yield could have been further increased if we had delayed harvest a few days.

Irrigation savings in the order of 40% were achieved with the compost plus clay treated plots and was largely due to the clay. The increased savings compared to the previous carrot crop (10%) that was grown through the summer period of high evaporative demand is likely to reflect the reduced irrigation frequency that is the result of both improved soil moisture holding associated principally with the clay and the reduced evaporative demand.

Control General view of trial site prior to harvest Clay + compost

Figure 3.3. Treatment differences in lettuce a few days before harvesting the second System site trial.

Broccoli, crop S-3

The third crop at the System site, broccoli, variety Mammoth, was planted on 7 August 2003 and was harvested on 20 October 2003.

Growing conditions

Reasonable rainfall was experienced during the 73 day broccoli crop and irrigation was significantly reduced due to the combination of rain and reduced evaporation. These conditions and the application of irrigation are summarised as weekly averages in Figure 3.4.

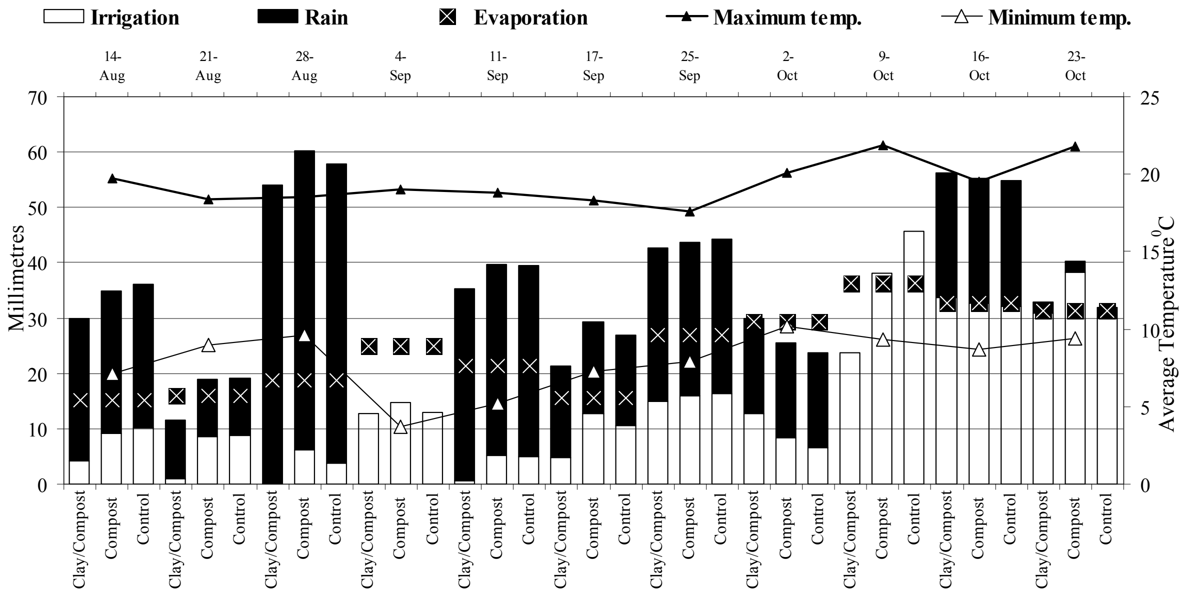


Figure 3.4. Average weekly weather conditions and irrigation application for the initial carrot crop at the system site.

Fertiliser program

In addition to the fertiliser program outlined in Table 3.17, 320 kg/ha of the standard trace element mix was applied. This was broadcast and incorporated with a rotary cultivator to 15 to 20 cm depth prior to crop establishment in conjunction with the application of Double Superphosphate.

Table 3.17. Fertiliser application to broccoli crop S-3 at the System site

Week N°.	kg/ha				
	P	N	K	Mg	Borax
Compost + clay	Nil	349.56	239.20	Nil	14.3
Compost	Nil	349.56	239.20	Nil	14.3
Control	25.0	347.66	297.38	20.95	15.38

Pest, disease and weed management

There were problems encountered during the life of the crop. The biological insecticide, Xentari® was applied to control Diamondback moth (*Plutella xylostella*) on 26 September and 3 October 2003.

Dacthat® was applied for weed control following transplanting on 8 August 2003.

Compost quality

The compost quality in the broccoli trial (Table 3.18) was very close to the specifications for vegetable crop use.

Table 3.18. Compost applied to broccoli crop S-3 at the system site

Analyt	Carbon Nitrogen Ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	NH_4 + NO_3	NO_3/NH_4 ratio
Critical value	*< 20*	*> 0.5*	*> 60*	*> 1.0*	*> 100*	*> 0.14*
Compost S-3	20	0.47	58	1.5	130	16

See Appendix 3.1 (Compost 12A) for more detailed analysis of all composts used at the system trial site.

Harvest

A successful crop of broccoli was grown and harvested weights are presented in t/ha Table 3.19.

Table 3.19. Marketable broccoli yields (t/ha) from the third crop at the System trial site at the Medina Research Station

Treatment	Marketable crop (t/ha)	Average head wt (g)	% increase in crop
Compost + clay	11.24	368.8	40.3
Compost	9.84	330.2	22.8
Control	8.01	266.2	0
lsd 1%	*1.17*	*7.9*	

Total and marketable broccoli head weights were significantly increased (P = 1%) by the application of compost and the clay amended plots increased the marketable crop by 40% compared to 23% with compost alone. This increase was the result of increased head weights.

Soil analysis

The trial site was sampled immediately after planting and the results are provided in Table 3.20. Soil bulk densities and volumetric moisture levels were determined 3 weeks after planting using procedures contained in the Department's 'Manual of Field Techniques in Hydrology' (Department of Agriculture Misc. Publication 37/91).

Table 3.20. Soil analysis (top 15 cm) at Planting of Broccoli on the System trial site (Treatment Means)

Analyte	Compost + clay	Compost	Control	lsd 5%
Ec (1:5 H_20)	9.0	7.25	4.0	1.26
pH ($CaCl_2$)	6.9	7.0	6.73	0.15
Org C %WB	0.48	0.34	0.34	0.14
N Total %db	0.035	0.023	0.017	0.005
NO_3 + NH_4 mg/kg	9.25	7.00	3.75	1.04
P Total mg/kg	218.0	145.0	113.0	13.2
P (HCO_3) mg/kg	102.5	73.0	58.2	13.1
K (HCO_3) mg/kg	101.8	78.3	15.8	10.2
Mehlich N^o. 3 extraction (mg/kg)				
Ca	765.0	515.0	435.0	ns
Mg	95.0	36.0	25.0	8
Fe	115.0	86.5	90.5	16
S	12.0	7.5	3.0	4.5
Cu	4.1	4.0	3.7	ns
Zn	8.0	6.9	6.0	ns
Mn	11.0	11.5	9.5	ns
B	0.45	0.20	0.35	ns
Mo	0.09	0.08	0.08	ns
Na	15.5	8.5	1.0	5.7

The soil carbon levels were very low at this site, however they increased significantly (P = 5%) from 0.34 to 0.48% with the application of clay. Soil fertility and other attributes increased with both compost and compost plus clay treatments with the largest increases associated with the addition of clay.

Apart from a significant (P = 5%) increase in bulk density associated with the clay plots, bulk densities have not increased, Table 3.21.

Table 3.21. Soil bulk density at three soil depths after two crops at the System site

Treatment	Soil depth cm		
	10-15	25-30	40-45
Compost + clay	1.635	1.620	1.569
Compost	1.539	1.548	1.577
Control	1.549	1.542	1.565
lsd 5%			
Within Treatments and Depth	*0.016*		
Treatment x Depth		*0.028*	

Clay had a considerable impact on volumetric soil water holding capacity, Table 3.22 shows compost plus clay almost doubled the volumetric water holding capacity in the top 15 cm of soil, however the small indicated increase associated with the compost only treatment was not significant (P = 5%).

Table 3.22. Volumetric soil moisture at three soil depths after two crops at the System site

Treatment	Soil depth cm		
	10-15	**25-30**	**40-45**
Compost + clay	16.69	18.82	7.46
Compost	9.11	9.01	7.09
Control	8.42	8.87	6.78
lsd 5%			
Within Treatments and Depth		*1.09*	
Treatment x Depth		*1.89*	

Foliar analysis

The results from nutrient analysis of outer wrapper leaves that were collected at harvest and analysed by Government Chemistry Centre in Perth, are presented in Table 3.23.

Table 3.23. Analysis of youngest fully matured broccoli leaves collected at harvest from the third trial at the System site

Analyt	Compost + clay	Compost	Control	lsd 5%	Normal
% db					
N	4.96	4.57	4.63	ns	4.5-4.8
P	0.70	0.62	0.64	ns	0.8-0.9
K	3.76	3.62	3.70	ns	3.5-4.2
Ca	1.23	1.10	1.10	ns	2.9-3.1
Mg	0.21	0.17	0.18	ns	0.48-0.54
S	1.21	1.14	1.20	0.01	
Na	0.15	0.17	0.18	ns	
mg/kg					
Cu	5.00	4.45	4.53	ns	3.0
Zn	44.50	42.00	42.00	ns	45-95
Mn	16.50	17.25	18.75	ns	25-150
B	34.25	32.50	34.25	ns	30-60
Fe	78.25	80.50	80.50	ns	
Mo	50.00	58.75	58.75	ns	0.3-0.5

* lsd - Least significant difference P = 0.05.
** Reuter, D.J. and Robinson, J.B. Plant analysis second edition CSIRO Publishing 1997.

There were very few differences in nutrient levels between treatments and of the minor or trace elements, manganese continued to be very low in all treatments. It was therefore unlikely that yield improvements were attributable to nutrient effects.

High levels of Molybdenum (~ 60 mg/kg) were recorded in all treatments. Because of concerns over low copper and manganese levels the standard Medina Trace element mix was broadcast before all three previous crops.

The Medina Trace element mix applies 2000 g of Sodium Molybdate (42.5% Mo) or 850 g of Mo per hectare. The recommended application for wheat in WA is 75 g Mo per hectare and we were adding more than 10 times this. We can calculate that 850 grams in the top 25 cm of soil will give soil concentrations of 0.227 mg Mo/kg and it is suggested that plant toxicities are likely at extractable levels above 0.2 mg/kg at soil pH above 6.8. The Medina site is running at 6.9 ($CaCl_2$) and while Molybdenum was not tested for in the pre plant soil analysis (Table 3.1), the leaf analysis results suggest that levels were potentially getting too high.

Irrigation

Irrigation applied in response to soil moisture levels are provided in Table 3.24 for each treatment along with the percentage irrigation plus rainfall that was collected in the lysimeters under each of the four replicates per treatment.

Table 3.24. Irrigation applied to the broccoli crop S-3 and the leachate collected at the System site

Treatment	Applied irrigation		Leachate collected	
	Total (kL/ha)	% Saving	% of applied	% Reduction
Compost + clay	1692	23.0	40.3	14.1
Compost	2284	-3.9	44.1	6.1
Control	2198	0.0	46.9	0.0

Irrigation savings were again associated with the compost + clay treatment and were smaller than the previous savings with the second lettuce crop.

Discussion

As with the previous trial, the broccoli produced was of very good quality and both compost treatments produced significantly higher yields (P = 0.01) of marketable heads. The addition of clay effectively doubled the increase associated with the compost on its own.

The impact of both compost treatments was most visibly demonstrated during seedling establishment when the compost plus clay treatment in particular exhibited faster establishment that was accompanied by better foliage colour (Figure 3.5).

Irrigation savings in the order of 20% were achieved with the compost plus clay treated plots and as with the previous trial, was due to the clay.

Clay + Compost General view of trial site prior to harvest Control

Figure 3.5. Improved broccoli seedling establishment associated with compost plus clay and the compost treatments.

Carrot – crop 4

Carrots, variety Stefano were sown on the 17 November 2003 and harvested on the 10 March 2004.

Growing conditions

Typical warm to hot summer growing conditions were experienced throughout the 119 day growing period of the second carrot crop. These conditions and the application of irrigation are summarised as weekly averages in Figure 3.6A and 3.6B.

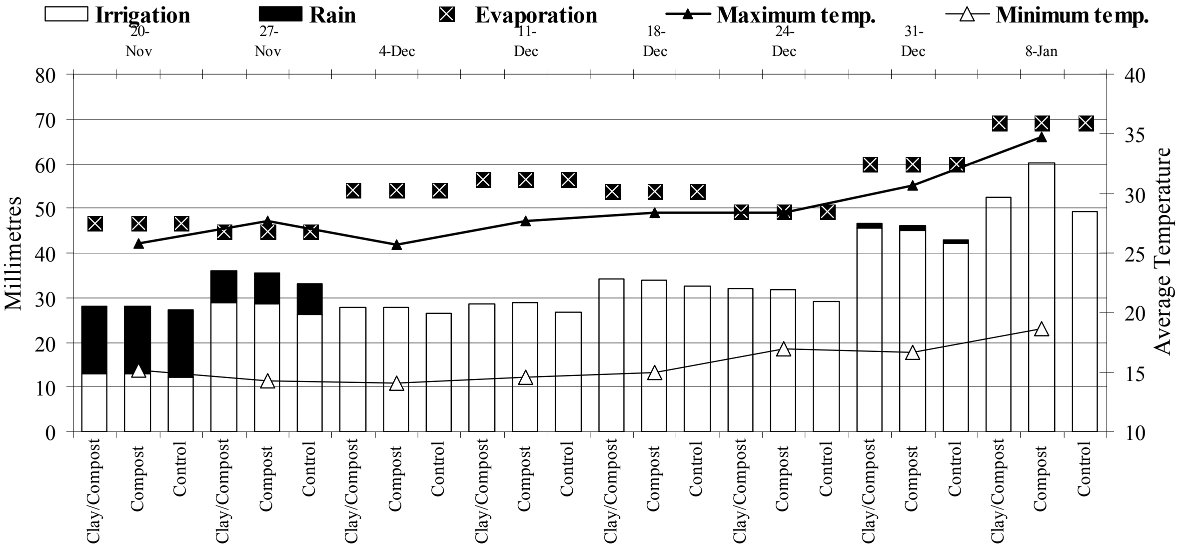


Figure 3.6A. Average weekly weather conditions and irrigation application for the initial November to early January period for the second carrot crop (S-4) at the system site.

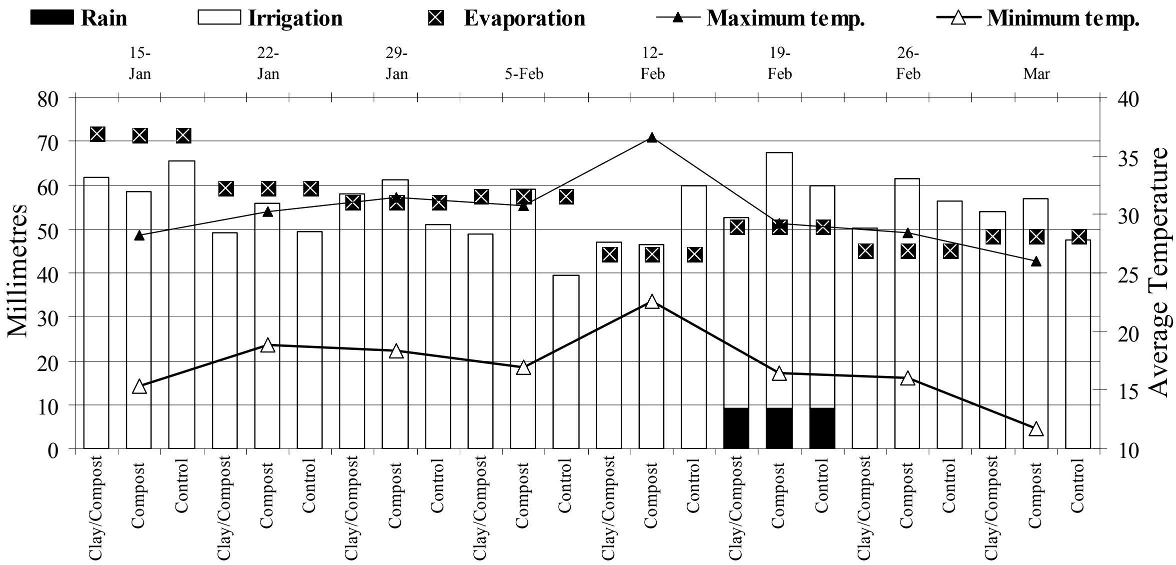


Figure 3.6B. Average weekly weather conditions and irrigation application for the final early January to early March period for the second carrot crop (S-4) at the system site.

Compared to the previous carrot crop (S-1) irrigation during the first half of the crop was considerably less.

Fertiliser program

In addition to the fertiliser program outlined in Table 3.25 and because of the high Molybdenum levels recorded on the previous crop (Table 3.23), 320 kg/ha of the standard trace element mix, without Sodium Molybdate was applied. This was broadcast and incorporated with a rotary cultivator to 15 to 20 cm depth prior to crop establishment in conjunction with the application of Double Superphosphate (control plots only).

As with the previous crop, no phosphorus was applied to the compost and compost plus clay plots.

Table 3.25. Fertiliser application to second Carrot crop (S-4) at the System site

Week N^{o}.	kg/ha				
	P	N	K	Mg	Borax
Compost + clay	Nil	250.24	234.80	Nil	15.10
Compost	Nil	250.24	234.80	Nil	15.10
Control	47.0	299.92	300.00	22.90	15.38

Pest, disease and weed management

The crop was again affected by nematodes (*Meloidogyne javanica*) although the severity was less than in the initial crop.

Apart from nematodes, there were no pest and disease problems and the standard pre-emergent herbicide (Afalon plus Triufluralin, Table 3.5) was applied at early crop emergence on 23 October 2002.

Compost quality

Apart from a low Nitrogen Drawdown Index of 0.21 and available nitrogen, the compost used exceeded the specifications set for the use of compost in vegetables (Table 3.26).

Table 3.26. Compost applied to Carrot crop S-4 at the system site

Analyt	Carbon Nitrogen Ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	NH4 + NO3	NO3/NH4 ratio
Critical value	*< 20*	*> 0.5*	*> 60*	*< 1.0*	*> 100*	*> 0.14*
Compost S-4	17	0.21	101	1.7	28	180

See Appendix 3.1 (Compost 13A) for more detailed analysis of all composts used at the system trial site.

Harvest, crop S-4

The carrots were hand harvested on the 10 March, washed and assessed for total and marketable yield (Grade A,B), and the results are summarised in Table 3.27. The crop was of poor quality with unacceptable levels of rejects across all treatments. While Nematodes contributed to the poor carrot quality poor shape was the greatest cause of carrots not meeting the Grade A,B standard and the incidence of forked roots and prominent eyes normally associated with nematode damage was far less than that experienced in the first crop.

Both compost treatments produced significantly (P < 0.05) greater total and marketable yields than the control. However total and marketable yields, particularly for the controls, were poor and less than those recorded in the first carrot crop.

Table 3.27. Total and marketable carrot yields (t/ha) from the fourth crop at the System trial site at the Medina Research Station

Treatment	Total	Marketable	% Misshapen	% Prominent eye	% Reject	Tops
Clay/Compost	67.5	25.7	32.3	22.6	63.5	20.37
Compost	71.1	26.9	50.1	8.6	62.7	15.79
Control	53.6	10.9	67.9	9.8	81.4	15.11
lsd (5%)	*5.78*	*6.73*	*7.57*	*5.42*	*8.25*	*1.37*

Soil analysis

At the completion of the trial the site was sampled to determine volumetric moisture (Table 3.28) and bulk densities (Table 3.29) using auger based procedures outlined in 'Manual of Field Techniques in Hydrology' (Department of Agriculture Misc. Publication 37/91).

Volumetric soil moisture content was increased by 40 to 65%, with the largest increase being associated with the addition of clay (Table 3.28). Bulk density was not affected by compost but was increased by the application of clay (Table 3.29).

Table 3.28. Volumetric soil moisture at the conclusion of the fourth crop at the System site

Treatment	Depth (cm)		% increase	
	0-15	15-30	0-15	15-30
Compost + clay	10.368	8.625	59.60	35.805
Compost	9.877	9.042	52.06	42.363
Control	6.496	6.351	0.00	0.000
lsd 5%	*1.108*			

Table 3.29. Soil bulk density at the conclusion of the fourth crop at the System site

Treatment	Depth (cm)		% increase	
	0-15	15-30	0-15	15-30
Compost + clay	1.619a	1.623a	-4.24	-4.537
Compost	1.546b	1.544b	0.43	0.537
Control	1.553b	1.552b	0.00	0.000

Values followed by a different letter are significantly different (P < 0.051).

Foliar analysis

Foliar analysis results of the youngest fully matured leaves that were collected at harvest and analysed by Government Chemistry Centre, Perth, are presented in Table 3.30.

Most analysis values were within the adequate range and there were no notable differences between the three treatments. Within all treatments, Manganese and copper continued to be low and low levels of Molybdenum, which was high in the previous Broccoli crop, were recorded.

Table 3.30. Analysis of youngest fully matured leaves at the harvest of the second carrot crop (S-4)

Analyt	Compost + clay	Compost	Control	lsd 5%	Adequate
% db					
N	3.275	3.4075	3.4025	ns	2.0-3.5
P	0.3025	0.2675	0.2975	0.018	0.2-0.35
K	4.1325	4.065	3.65	0.29	2.5-4.5
Ca	2.3875	2.53	2.725	0.26	1.4-3.0
Mg	0.415	0.3875	0.4	ns	0.3-0.55
S	0.475	0.42	0.465	0.042	0.32-0.63
Na	0.665	0.59	0.72	ns	0.66-4.5
mg/kg					
Cu	4.67	4.25	2.98	0.78	10-25
Zn	22.50	17.00	17.50	4.80	20-50
Mn	24.50	21.20	23.50	ns	130-350
B	50.50	53.20	56.00	2.20	30-80
Fe	235.00	198.00	210.00	ns	120-350
Mo	4.67	4.25	2.98	0.78	10-25

* lsd - Least significant difference P = 0.05.
** Reuter, D.J. and Robinson, J.B. Plant analysis second edition CSIRO Publishing 1997.

Irrigation

Volumes of irrigation applied in response to soil moisture levels are reported in Table 3.31 for each treatment along with the percentage irrigation plus rainfall that was collected in the lysimeters under each of the four replicates per treatment.

Table 3.31. Irrigation applied to the second carrot crop (S-4) and the leachate collected at the System site

Treatment	Applied irrigation		Leachate collected	
	Total (kL/ha)	% Saving	% of applied	% Reduction
Compost + clay	9,567	-2.4	3.55	54.6
Compost	10,242	-9.7	9.78	-25.5
Control	9,340	0.0	7.79	0.0

As indicated, the control treatment received the least irrigation and this was only slightly less than the irrigation applied to the compost plus clay treatment and was almost 10% less than applied to the compost only treatment.

This problem with the control carrots being under watered is again illustrated by the mid crop soil moisture recordings over two weeks that were provided by four TDR's located in the top 20 cm of soil in each plot. The averaged results for the control and compost + clay plots are provided in Figure 3.7.

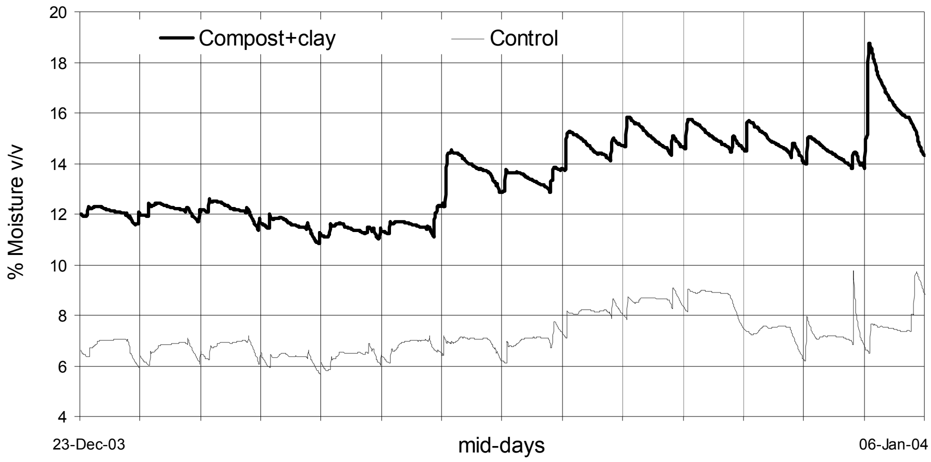


Figure 3.7. Averaged % volumetric soil moisture recorded from TDR's located in the top 20 cm of soil in the control and compost + clay plots at the initial System trial.

Discussion

Although reduced, the nematode problem continued to affect the second crop of carrots.

Carrot yields (Table 3.26) and particularly marketable yields were less than recorded during the earlier carrot crop (S-1, Table 3.8) and the reduction was most noticeable for the control treatment.

The growing condition charts, 3.6A and B, as well as a review of soil moisture recordings from the TDR's (Figure 3.7) confirm that all treatments and in particular the control treatments were under watered.

The irrigation problems will have resulted in considerable stress, particularly for the control treatments and would explain the differences recorded in carrot quantity and quality (Table 3.26). Figure 3.7 also confirms that volumetric moisture levels, at least in the controls, were significantly below field capacity that is generally considered to be 10% in these soils.

Volumes of irrigation applied to the two carrot crops are compared in Table 3.32 with averaged weekly evaporation which was 9.5% less in the second crop. Even when we correct the applied irrigation for the reduced evaporation, the control plots received almost 20% less irrigation than in the earlier crop.

Table 3.32. Comparison of evaporation and irrigation applied to two carrot crops (S-1 and S-2) at the System site

Treatment	Averaged evaporation (mm)		Irrigation (kL/ha)		% Irrigation reduction	Corrected % irrigation reduction
	S-1	S-4	S-1	S-4		
Compost + clay			11,296	9,567	15.3	6.4
Compost	59.8	54.1	12,289	10,242	16.7	7.9
Control			12,754	9,340	26.8	19.1

The irrigation problems experienced, meant that although clay leached less water (Table 3.31) the 11.0% irrigation savings recorded with the first carrot crop (Table 3.11), were not repeated in this trial.

The marked difference in volumetric soil moisture measurements between control and the compost plus clay treatment, also highlight a potential concern with the automated management system that triggered irrigation in all treatments at the same soil moisture tension. This approach clearly illustrates that the altered physical nature of the soils associated with the different treatments impacted on volumetric soil moisture levels and resulted in higher soil moisture levels being maintained in the clay treatment (Figure 3.7). Clearly a better approach would have been to use individually derived trigger points for each treatment based on soil moisture calibration curves.

Lettuce Crop S-5

The final crop at the System site was lettuce, variety Oxley that was transplanted on 1 April 2004.

Growing conditions

Reasonable rainfall was experienced during the 57 day lettuce crop and irrigation was significantly reduced due to the combination of rain and reduced evaporation. These conditions and the application of irrigation are summarised as weekly averages in Figure 3.8.

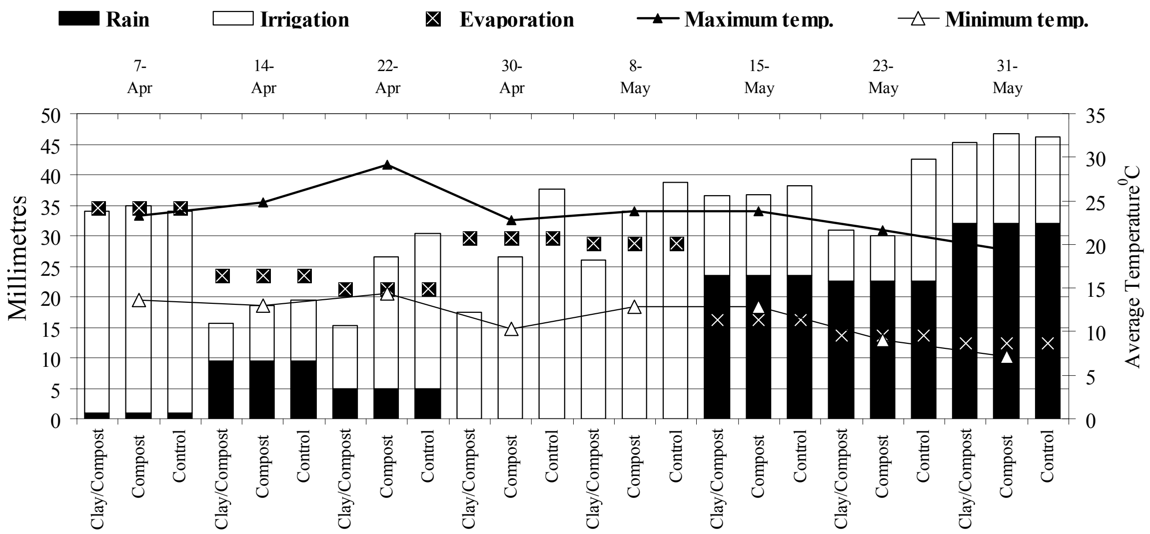


Figure 3.8. Average weekly weather conditions and irrigation application for the final lettuce trial (S-5) at the system site.

Fertiliser program

In addition to the fertiliser program outlined in Table 3.33, 320 kg/ha of the standard trace element mix, without Sodium Molybdate was applied. This was broadcast and incorporated with a rotary cultivator to 15 to 20 cm depth prior to crop establishment in conjunction with the application of Double Superphosphate (control plots only).

Table 3.33. Fertiliser application to final lettuce crop (S-5) at the System site

Week N^o.	kg/ha				
	P	N	K	Mg	Borax
Compost + clay	180.0	336.0	227.8		15.10
Compost	180.0	336.0	227.8		15.10
Control	250.0	336.0	266.0	23.6	15.38

As discussed earlier, the final lettuce crop was grown using a modified fertiliser program that was outlined in Table 3.3 (Phillips 2003).

Pest, disease and weed management

There were no pest or disease problems encountered during the life of the crop. The herbicide Kerb® was applied after transplanting the seedlings on 6 April 2004.

Compost quality

The compost quality in the lettuce trial (Table 3.34) was good quality with only Nitrogen Draw Down Index being outside of the recommended specifications.

Table 3.34. Compost applied to the final lettuce crop (S-5) at the system site

Analyt	Carbon Nitrogen Ration	Nitrogen Drawdown Index	Toxicity	Total Nitrogen	NH_4 + NO_3	NO_3/NH_4 ratio
Critical value	*< 20*	*> 0.5*	*> 60*	*1.0*	*> 100*	*> 0.14*
Compost S-5	17	0.4	43.0	1.6	280.0	> 280

See Appendix 3.1 (Compost 14A) for more detailed analysis of all composts used at the system trial site.

Harvest

In order to detect possible treatment influences on crop development, the lettuce were harvested over three dates and total and marketable head yields are provided in Table 3.35.

Table 3.35. Total and marketable lettuce yields (t/ha) from the second crop (S-5) at the System trial site at the Medina Research Station

Treatment	Harvest 1		Harvest 2		Harvest 3	
	Total	Marketable	Total	Marketable	Total	Marketable
Compost + clay	52.72	29.33	63.31	34.86	64.74	37.60
Compost	51.81	29.20	59.64	33.98	64.65	38.45
Control	56.60	31.91	64.91	37.96	67.67	39.44
lsd (P 1%)	*2.48*	*1.77*	*2.71*	*1.80*	*ns*	*ns*

Over the first two harvests, the control treatment produced significantly better yields (P 1%) both in terms of total plant weight and marketable head, however these declined by the third and final harvest when there were no significant differences between all treatments.

Soil analysis

Plots were soil sampled at planting of the trial and were analysed at the Government Chemistry Centre. The results are provided in Table 3.36.

With the exception of soluble nitrogen, the clay plus compost treatment increased all aspects of soil quality more than compost alone. This would be expected because of its influence on soil particle size and cation exchange. The reduced physical particle size would have also contributed to increasing retention of soil carbon (clay – 0.73; compost alone – 0.57; control – 0.35% db) and this inturn; will have contributed to the improvements in soil quality recorded. The higher soluble nitrogen levels associated with the compost alone suggest that higher mineralisation was occurring due to the less protected soil environment.

Table 3.36. Soil analysis, at two depths at planting of the final crop (S-5) at the System site

Analyt	Compost+clay		Compost		Control		0-15 cm	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	Prob.	*5% lsd*
EC (1:5 H_20)	17.75	25.5	15.0	14.75	8.0	9.25	< 0.001	2.87
pH ($CaCl_2$)	7.3	7.15	7.23	7.05	6.95	6.88	< 0.001	0.096
Org C (% WB)	0.73	0.55	0.57	0.47	0.35	0.34	< 0.001	0.119
N Total %db	0.056	0.040	0.041	0.029	0.013	0.014	0.002	0.007
$NO_3 + NH_4$ mg/kg	12.75	18.0	13.75	13.25	3.75	4.75	0.002	4.35
P Total mg/kg	390.0	252.5	315.0	220	160.0	150.0	< 0.001	41.6
P (HCO_3)	177.5	147.5	135.0	110.5	95.3	99.8	0.004	32.8
K (HCO_3)	210.0	111.5	120.0	48.5	21.3	23.3	< 0.001	23.2
Ca me%	7.02		5.5		2.3		< 0.001	0.76
Mg me%	1.27		0.60		0.31		< 0.001	0.1
Na me%	0.48		0.26		0.12		< 0.001	0.08
K me%	0.53		0.29		0.05		< 0.001	0.055
Total exch cation	9.29		6.62		2.77		< 0.001	0.875

Total nitrogen accumulation is presented graphically in Figures 3.9. The quantities of nitrogen in the top 30 cm of soil was calculated from the analysis data in Table 3.27 and has been reduced by the amount present prior to the commencement of the trials. The quantity of nitrogen applied in the five compost applications is also shown. The addition of clay increased the retention of nitrogen applied as both fertiliser and compost and a percentage of the nitrogen applied as inorganic fertiliser was retained.

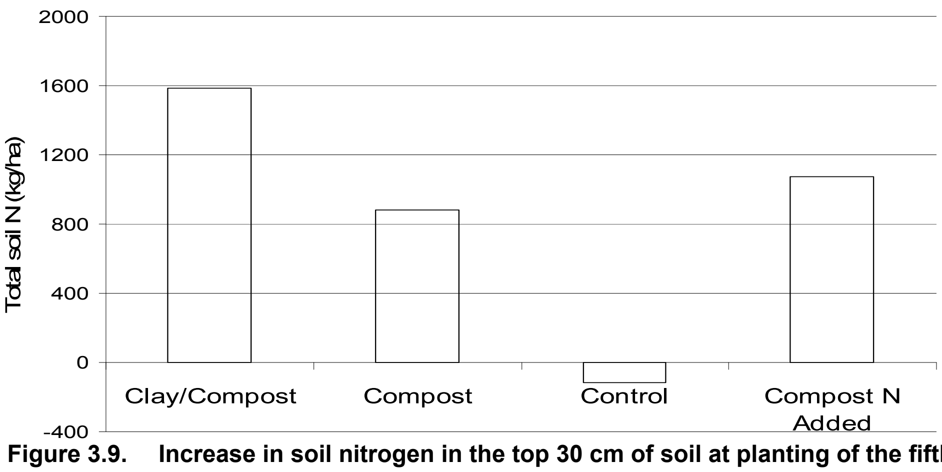


Figure 3.9. Increase in soil nitrogen in the top 30 cm of soil at planting of the fifth crop compared to the quantity applied by compost.

Compost alone showed reduced nitrogen loss. The negative value for the control treatment represents a net loss of 116 kg/ha over the four crops in the absence of added compost.

Soil bulk densities (Table 3.29) and a field capacity of 10% volumetric water can be used to show that at planting the calculated level of soluble nitrogen in the top soil (0 to 15 cm) of compost treated plots was above 200 ppm (Table 3.37). This level is considered the upper limit for nitrate nitrogen in hydroponic solutions and suggests that at this time, sufficient mineralisation was occurring to establish the lettuce crop.

Table 3.37. Soil nitrogen levels in top 15 cm of soil at planting of the fifth crop at the System site

Treatment	Total Nitrogen		Soluble (NH_4 + NO_3) Nitrogen		
	%db	kg/ha	mg/kg	ppm @ 10% soil moisture	% Increase
Control	0.013	326.1	3.75	58.24	0.0
Compost	0.041	950.8	13.75	214.56	265.0
Compost + Clay	0.056	1360.0	12.75	206.42	254.4

Soil carbon levels at the time of planting the fifth crop are presented graphically in Figure 3.10. The carbon present in the top 30 cm of soil was calculated from bulk density Table 3.29 and the analysis data in Table 3.30. Quantities of carbon applied in the five compost applications is also shown and suggests that while a percentage of the carbon added by compost is used by biological respiration processes gains have been significant with clay almost doubling the retention of carbon.

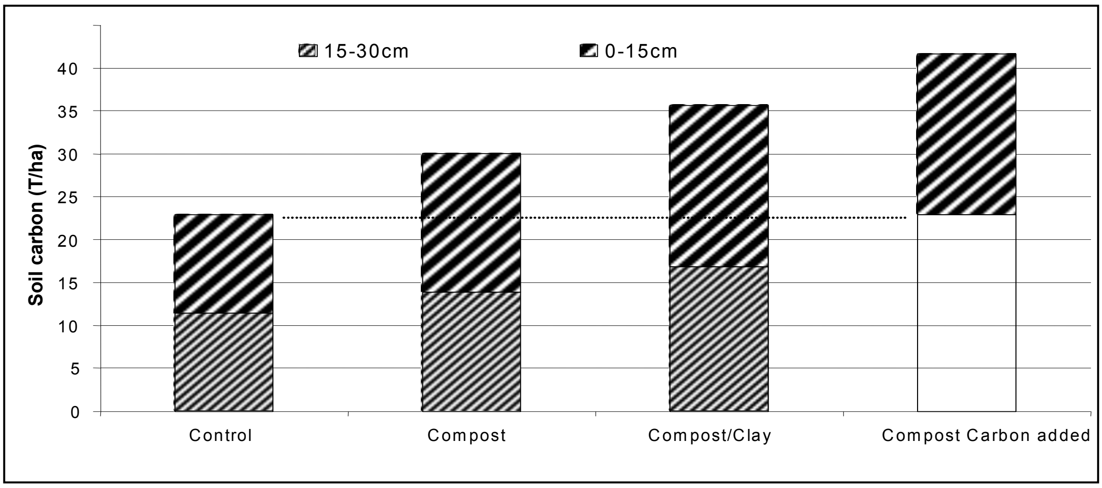


Figure 3.10. Summary of soil carbon in the top 30 cm of soil at planting of the fifth crop on the System site compared with the quantity applied in compost.

These results are summarised in Table 3.38 and suggest that the applications of five 30 m^3/ha applications of compost with or without the additional clay amendment are making a significant impact on the retention of both nitrogen and carbon in the soil.

Table 3.38. Summary of impacts of treatments at the System site on soil nitrogen and carbon at planting of the fifth crop

Soil content kg/ha	Compost+clay	Compost	Control	Pre trial
Nitrogen 0-15 cm	1,356	941	302	370
Nitrogen 15-30 cm	962	670	314	362
Total Nitrogen gain	1586	879	-116	
% Nitrogen retained	148	82	-11	
Carbon 0-15 cm	16,800	13,900	11,400	n/a
Carbon 15-30 cm	18,900	16,200	11,500	n/a
Total carbon	35,700	30,100	22,900	n/a
% Carbon retained	78.7	42.7		

Foliar analysis

The results from nutrient analysis of outer wrapper leaves that were collected at harvest and analysed by Government Chemistry Centre in Perth, are presented in Table 3.39.

Table 3.39. Analysis of outer wrapper leaves collected at harvest of the final lettuce trial at the System site

Analyt	Compost + clay	Compost	Control	lsd 5%	Adequate
% db					
N	3.67	3.74	3.80	ns	3.3-4.0
P	0.60	0.52	0.65	0.07	0.4-0.6
K	6.00	5.62	4.64	0.44	5.0-8.0
Ca	0.63	0.61	0.61	ns	1.4-2.0
Mg	0.24	0.24	0.24	ns	0.3-0.7
S	0.19	0.18	0.18	ns	0.3-0.32
Na	0.72	0.65	0.60	0.09	0.5-1.0
mg/kg					
Cu	7.45	6.65	6.40	ns	43374.00
Mn	20.25	26.00	52.50	7.90	50-300
Zn	43.50	36.75	48.25	5.70	30-100
B	23.75	24.75	23.75	ns	25-55
Fe	192.50	227.50	227.50	ns	50-500

* lsd - Least significant difference P = 0.05.
** Reuter, D.J. and Robinson, J.B. Plant analysis second edition CSIRO Publishing 1997.

Apart from lower Manganese values in both the compost treatments, there are no obvious differences in the nutrient content of the outer wrap leaves that were collected during the first harvest.

Irrigation

Irrigation applied in response to soil moisture levels are provided in Table 3.40 for the compost/clay and compost treatment along with averaged leachate that was collected under each of the four replicates per treatment. After the first 2 weeks control plots received 150 per cent of evaporation over 2 waterings each day.

Table 3.40. Irrigation applied to the final lettuce crop (S-5) at the System site and the leachate collected

Treatment	Applied irrigation		Leachate collected	
	Total (kL/ha)	% Saving	Total (kL/ha)	% Reduction
Compost + clay	8,475	31.7	37.06	22.1
Compost	9,575	22.9	39.64	16.6
Control	12,416	0	47.55	0

Considerable savings were achieved with the compost plus clay treatment and the compost only treatment also used less water. The leachate collected was similarly reduced.

Discussion

Compost, despite promoting high levels of plant available nitrogen did not result in increased lettuce yield. This may have resulted from:

- The refined inorganic nitrogen fertiliser program that was applied to all treatments in the trial. The program applied frequent spray applications of nitrogen during the initial establishment weeks and is likely to have maintained nitrogen within the root zone of the establishing crop as effectively as the compost treatments were able to.
- The reduced rainfall experienced for this crop causing less leaching.
- Restricted watering of the crop.

Both the compost and compost plus clay treatments also appeared to delay lettuce growth. This is supported by the consistent trend for the compost and compost plus clay treatments to increase yields over the three successive harvests (Table 3.35) and suggests that higher yields would have been achieved by compost treated plots if harvested later than 28 May 2004.

Irrigation savings of 32% and 23% respectively were achieved with the compost plus clay and the compost alone treatment without yield reduction.

Conclusions

With the exception of carrots, crop performance has been improved by compost and compost plus clay. The carrot results were confounded by nematode (*Meloidogyne javanica*) infestation, marginal compost quality and irrigation problems. Because of their small seed size and therefore reduced nutrient reserves; the impact of compost quality is probably greater on carrots than transplanted crops such as lettuce and broccoli (Paulin 2000A).

Over the five trials increasing savings in fertiliser and irrigation use have been demonstrated. Both compost treatments have increase soil fertility in terms of soil carbon and nitrogen levels, volumetric water holding and cation exchange capacity. However because of the extremely low initial levels, we were not able to test the potential for the clay to increase soil carbon above that achieved at the Nitrogen Replacement site.

The improvements in soil nitrogen storage has been associated with reduced nitrogen leaching, although it must be acknowledged that unless overall fertility that includes carbon suitable for sustaining microbial populations is maintained, it will eventually be lost.

The important outcome is that the regular use of compost builds soil nitrogen reserves and that through mineralisation, these reserves can buffer nitrogen availability in the soil solution, and minimise leaching losses that are inevitably associated with:

- rainfall events;
- inappropriate irrigation management; and
- periods when conventional sprinkler irrigation makes it impossible to avoid leaching such as during crop establishment.

The indicated irrigation savings with the compost plus clay have ranged from 40% during the cool winter periods to less than 10% during summer months when high evaporative conditions combined with the low moisture holding capacity and hydraulic conductivity of these coarse sands, prevents significant reduction in daytime irrigation. At this time, it would appear that irrigation savings in the order of 20% are possible with the use of clay and that smaller savings possibly approaching 10% are possible with compost alone. The economic considerations of these management savings are discussed in 'Section 9, Overall project discussions', towards the end of this report and more detailed discussion of these findings follow.

Crop performance

Marketable crops from the five consecutive trials are provided in Table 3.41 and show that compost and compost plus clay have generally increased yields. The susceptibility of carrots to poor compost quality and the irrigation problems with the second carrot crop (S-4), potentially reduced potential improvements.

Yield improvements with lettuce and broccoli at the System site and mainly lettuce in the earlier nutrient replacement trials are at least in part explained by mineralisation of organic nutrient reserves associated with compost application. During periods of rain, relatively infrequent applications of inorganic fertilisers associated with current practices are unable to maintain adequate nutrient concentrations, particularly within the restricted root zone of establishing crops. Our findings support a view that mineralisation of the inorganic nutrient reserves are better able to maintain uniform levels of available nitrogen and other soluble nutrients and will be supported by the regular use of compost.

The final lettuce crop (S-5) supports this hypothesis. Noting the overall similarity with the initial lettuce crop (S-2), the lack of response to compost and compost plus clay treatments in this crop, is likely to have been the result of the improved fertiliser program that applied more frequent nitrogen applications during the initial establishment weeks and the lack of leaching rains that were experienced during the first lettuce crop.

Table 3.41. Summary of marketable yields from the five crops grown at the System trial site

Treatment	Carrot S-1	Lettuce S-2	Broccoli S-3	Carrot S-4	Lettuce S-5
Compost + clay	17.2	44.20	11.24	25.7	37.60
Compost	30.5	46.42	9.84	26.9	39.44
Control	34.4	41.70	8.01	10.9	39.44
lsd (P 5%)	*8.6*	*2.030*	*1.12*	*6.73*	ns

The use of compost therefore provides an alternative to the option of applying nitrogen in small more frequent applications during crop establishment. This will reduce, if not eliminate, the additional management requirements and will also reduce the potential leaching losses that will inevitably be associated with a fertigation approach when overhead irrigation is required.

Irrigation

Volumes of irrigation applied to each crop and each treatment, provided by flow meters, along with Epan evaporation and rainfall is provided Table 3.42.

Table 3.42. Irrigation (kL) applied to five trials at the system site along with relevant climate information

Trial	Irrigation applied (Kl)						Weather data			
	Compost + clay	Compost	Control	Saving*	%* saving	Total	Evap mm	R'nf mm	Days	Daily evap
S1	11,296	12,287	12,754	1,458	11.4	36,337	945	35.4	120	7.88
S2	1,043	1,588	1,741	698	40.1	43,720	147	216	55	2.67
S3	1,692	2,284	2,198	506	23.0	6,174	269	211	73	3.68
S4	9,567	10,242	9,340	-227	-2.4	29,149	907	33.2	119	7.62
S5	848	958	1,242	394	31.7	30,466	180	93.4	57	3.16
Totals	24,446	27,359	27,275	2,829	10.4	145,846	2,448	589.0	424	5.77

* Savings associated with the compost plus clay treatment.

Growing condition charts provided for each trial indicate the critically important relationship between evaporative conditions and applied irrigation plus rainfall. With the exception of the second carrot crop (S-4), they indicate that the evaporation replacement values for the crop, considering its growth stage and the time of year, were acceptable.

Irrigation savings associated with the compost only treatment were not recorded until the third crop and were not significant until the final crop when it resulted in a 25% reduction compared to the volume applied to the control treatment.

The overall reduced savings associated with summer irrigation (S-1 and 4) highlights recognition that savings in crop water use are only be achieved by:

- Minimising wastage through improving application efficiency; and
- Reducing evaporative losses by reducing application frequency – in other words through improving soil water holding capacity or the use of protective structures to reduce evaporative demands.

We have demonstrated that regular use of compost improves the water holding in our coarse sandy soils; however it is clear from this work that the increases achieved were insufficient to significantly reduce the number of applications required during periods of high evaporative demand. This includes summer and a proportion of the spring and autumn periods and is because the daily water requirement cannot be met from stored water reserves. Consequently the need to apply water more than once each day remained. When the soil has been amended with the addition of 200 t/ha of clay, significant savings are possible during cooler periods while reductions during the summer period are much less and are likely to be in the order of 10%.

The important factor is hydraulic conductivity or the capacity of the soil to deliver moisture into the active root zone as it is depleted by the plant. Our results suggest that the improvements to soil moisture holding and hydraulic conductivity achieved to date have been modest and that we need to achieve considerable further improvements to soil carbon levels.

These considerations need to be tempered by discussion of the second carrot crop, S-2, and recognition that triggering irrigation with the same minimum soil tension for all treatments may not have been the best approach. However, it is likely that this approach reduced rather than increased potential irrigation savings because it may not have fully used the stored soil moisture reserves associated with the different treatments (Table 3.45).

Nitrogen leaching

Samples of leachate solution were routinely frozen following the weekly collection. Nitrogen concentration was measured, prior to freezing, on the samples collected from the final two trials (S-4 and S-5) using an RQ Flex® meter.

Immediately prior to establishing the final crop the control plot irrigation was accidentally triggered overnight and operated for several hours before being discovered. This caused 150 kg/ha of nitrogen to be leached from the control plots and data from almost 10 months of continuous weekly sampling prior to this is presented in the belief that it more fairly represents the situation. The nitrogen collected in lysimeters over the period of 282 days has been expressed as kg/ha in Table 3.43 and compared to the unamended controls. The compost plus clay and compost alone treatments have reduced nitrogen losses by 26.0% and 13.8% respectively.

Table 3.43. Nitrogen collected in leachate over 280 days from October 2003 to August 2004

Treatment	Total leached kg/ha	Savings kg/ha	% Reduction
Compost+clay	250.98	87.96	26.0
Compost	292.29	46.65	13.8
Control	338.94	0.00	0.0

This supports the soil analysis data (Figure 3.9) and the reductions in total leachate that has been expressed as a percentage of the irrigation and rainfall collected in rain gauges that were associated with each Lysimeter (Table 3.44).

Table 3.44. Leachate expressed as percentage of the irrigation and rainfall applied to each crop at the system trial site

Crop	Season	Leachate as % of irrigation + rainfall			% Saving*
		Compost + clay	Compost	Control	
Carrot	Summer	10.13	23.4	20.1	49.5
Lettuce	Autumn	47.5	55.0	54.4	12.8
Broccoli	Winter - spring	40.3	44.1	46.9	14.1
Carrot	Summer	3.55	9.78	7.99	54.5
Lettuce	Autumn	35.8	38.9	47.5	24.6

* Reduction associated with compost plus clay treatment expressed as percentage of control.

Soil quality and performance

As previously discussed, the compost plus clay treatment gave significant improvements in the range of soil fertility as well as physical and chemical attributes measured.

A comparison of soil quality following planting of the first and fifth crops (compost applications at 30 m^3/ha) is provided in Table 3.45. It should be noted that comparisons of volumetric water and in particular, bulk densities are clouded by the different sampling time with respect to the cropping cycle. Different approaches to sample collection that involved traditional metal rings in the first sample and the use of an auger in the second to obtain standard volumes of soil are both acceptable techniques and accurately applied give close agreement with each other. The difference in volumetric water measured during the Broccoli crop (S-4) and that measured after the carrot crop (S-5) is a function of procedure and season and comparisons over time are not valid.

Exchangeable cations have increase almost three fold following the fifth compost application to the clay amended plots and this is reflected in the much higher potassium levels compared to control (Table 3.36).

Table 3.45. Comparison of soil fertility, chemical and physical properties at planting of the third and fifth crops at the system site.

Analyte	Crop S-3			Crop S-5		
	Compost + clay	Compost	Control	Compost + clay	Compost	Control
Organic C (% WB)	0.48	0.34	0.34	0.73	0.57	0.35
Total Nitrogen (%db)	0.036	0.023	0.017	0.056	0.041	0.013
$NO_3 + NH_4$ Nitrogen (mg/kg)	9.25	7.00	3.75	12.75	13.75	3.75
Total exchangeable cations				9.29	6.62	2.77
pH ($CaCl_2$)	6.9	7.0	6.7	7.30	7.23	6.95
Volumetric water (%w/v) [0-15 cm]	16.69	9.11	8.42	10.368	9.877	6.496
Bulk Density (t/m^3) [0-15 cm]	1.635	1.539	1.549	1.619	1.546	1.553

Soil analysis values for inorganic nitrogen (Table 3.36) were used together with Bulk density values from Table 3.29 to estimate likely Nitrate nitrogen concentration in the soil solution at a field capacity of 10%v/v (Table 3.46).

Considerable mineralisation is indicated by the soil solution nitrogen levels being in the order of 200 ppm.

Table 3.46. Inorganic ($NO_3 + NH_4$) nitrogen present at commencement of the final crop (S-5) at the System site

Inorganic nitrogen	Compost + clay		Compost		Control	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
$NO_3 + NH_4$ mg/kg	12.75	18.00	13.75	13.25	3.75	4.75
$NO_3 + NH_4$ ppm	206.6	291.6	211.8	204.1	58.1	73.6

Compost quality

With the exception of the compost used in the first carrot crop, quality was generally good and met the criteria that we set at the commencement of the project (Table 3.47). However there are individual anomalies that highlight the important message that no single aspect of compost quality can determine its performance. The Nitrogen Drawdown Index was universally below the stated critical value of greater than 0.5. This drawdown index is a measure of the presence of undecomposed carbon and hence reflects a potential for the compost to compete with the crop for available nitrogen. However there are several factors that are likely to influence whether this will occur, including the:

- Nature of the crop, small seeded carrots being more susceptible that transplanted cell pack seedlings.
- The level and nature of soluble nitrogen within the soil solution. Levels above 100 mg/kg and the dominance of nitrate nitrogen is likely to reduce the potential negative impact of a low Nitrogen Drawdown Index value.

Table 3.47. Average quality parameters, considered most relevant to the performance of compost in vegetable production, of the 5 composts used on the System site

Analyte	Critical value	Unit	Average
Carbon Nitrogen Ration	< 20	none	19.4
Nitrogen Drawdown Index	> 0.5	none	0.4
pH ($CaCl_2$)	5-7.5	pH units	7.5
Toxicity (potting mix test)	> 60	%	75.5
Moisture content		n/a	36.2
Total Nitrogen	> 1.0	% DM	1.5
NH_4 + NO_3	> 100	mg/L	163
NO_3/NH_4 ratio	> 0.14	(m/L)	98

Appendix 3.1. Analysis of the compost used in the System trial site at the Medina Research Station. Samples collected immediately before compost application and analysed to AS 4454 specifications by Collex Laboratories, Adelaide, SA.

Analyte	Critical/ ideal value	Unit	Compost sample				
			10A (S 1) Carrot	11A (S 2) Lettuce	12A (S 3) Broccoli	13A (S 4) Carrot	14A (S 5) Lettuce
Carbon Nitrogen Ration	< 20/< 17	none	25	18	20	17	17
Nitrogen Drawdown Index	> 0.5	none	0.37	0.36	0.47	0.21	0.4
Organic matter		% DM	51	53	50	49	46
pH ($CaCl_2$)	5 - 7.5	pH units	7.8	8.1	7.2	7.2	7
Electrical conductivity	-	dS/m	1.35	7.95	3.75	7.50	7.5
Toxicity (potting mix test)	> 60	%	100	< 5.0	58	101	43
Moisture content		n/a	43	35	42	33	28
Total Nitrogen	1.0/1.4	% DM	1.2	1.7	1.5	1.7	1.6
Organic nitrogen		% DM					
NH_4 + NO_3	> 100	mg/L	78	300	130	28	280
NH_4 nitrogen		mg/L	78.0	300.0	7.4	6.1	< 1.0
NO_3/NH_4 ratio	> 0.14	(m/l)	< 0.10	< 0.10	16.00	180.00	> 280
Phosphorous - Total (P)		% DM		1.0	0.9	1.0	0.24
Phosphorus - Soluble	< 0.5	mg/L		18	10	4.8	3.7
Potassium (K)		% DM	0.36	1	0.5	0.64	0.83
Calcium (Ca)		% DM	10.0	6.2	7.8	6.4	6.4
Magnesium (Mg)		% DM	0.29	0.45	0.36	0.32	0.38
Manganese (Mn)		mg/kg		260			310
Zinc (Zn)		mg/kg		320			270
Copper (Cu)		mg/kg		150			110

SECTION 4 SYSTEMS TRIAL – VICTORIA

Introduction

In this trial, improvements in productivity and soil physical and chemical characteristics were monitored through the application of different soil amendments and management practices to vegetables at DPI Knoxfield. This trial investigated the effects of a green manure crop in combination with soil amendments as well as the effect of timing of compost application. Both green manure crops and composts are known to be good sources of organic manure and their use in combination may be particularly beneficial in improving the physical, chemical and biological properties of soil.

Similarly to the NR-trial, 2 composts were used but grease trap compost (GTC) was used instead of food waste compost (FWC). GTC was made up of a mixture of the residual sludge after the skimming and static de-watering of grease trap waste and blended with sawdust and straw prior to composting.

Materials and Methods

Trial site at DPI Knoxfield

For a general description of the trial site at DPI Knoxfield, see 'Section 2 – Fertiliser Replacement Trials – Victoria'.

Trial design

A randomised complete block design was used that was aimed at partially balancing the treatments across 5 blocks. There were 9 main treatments that included a control, poultry manure, green manure crop and 2 types of compost (GTC and SGWC) at 2 different application and rates (15 m^3/ha and 45 m^3/ha). The lower rate of compost was applied in split applications (15 m^3/ha before each crop) whereas the higher rate of compost (45 m^3/ha) was applied initially and only again after 3 crop cycles (Table 4.1).

Table 4.1. Treatment description and rates for Systems-trial

Abbreviation	Amendment	Rate and timing
C	Control	No amendment
PM(45/3)	Poultry manure	45 m^3/ha prior to first of 3 crops
GTC(45/3)	Grease-trap compost	45 m^3/ha prior to first of 3 crops
SGWC(45/3)	Soft green waste compost	45 m^3/ha prior to first of 3 crops
GTC(15)	Grease-trap compost	15 m^3/ha prior to every crop
SGWC(15)	Soft green waste compost	15 m^3/ha prior to every crop
GTC(GM)	Grease-trap compost + green manure crop	45 m^3/ha prior to first of 3 crops; Green manure crop grown over summer
SGWC(GM)	Soft green waste compost + green manure crop	45 m^3/ha prior to first of 3 crops; Green manure crop grown over summer
GM	Green manure crop	Green manure crop grown over summer

Trial set-up and maintenance

The compost and poultry manure was measured out by filling up the appropriate amount in one or two 20 L white buckets before being applied to individual plots (sown area), raked out and rotary hoed in by the tractor.

Pre-packaged poultry manure was bought from a local nursery and applied to the plots similarly to the compost treatments above. A sample was also sent to DPI Werribee for analysis. A green manure crop containing a forage blend of legumes and cereals (Biomax™) was sown over summer (in between broccoli and lettuce crops). The sowing of the second green manure crop was not successful despite it being re-sowed. It's establishment was affected by bird damage.

Two pre-emergent herbicides were used. Dual Gold (960 g/L S-Metalochlor) from Novartis was applied to broccoli by a boom spray on the back of a tractor at approximately 4 L per hectare either prior to or within one week of transplanting. This was then watered in for 1-2 hours with overhead sprinklers or by rain. Similarly Stomp 330E (330 g/L Pandemethalin) was applied prior to transplanting lettuce at approximately 4 L per hectare in a similar fashion. Weeds were a minor problem in the first lettuce crop however were generally controlled by hand weeding and hoeing.

For the first crop, a Hamilton tree-planter was used to hand plant broccoli seedlings but for the next 2 crops a cup-transplanter was used to mechanically plant the broccoli and lettuce seedlings.

All four crops were affected in some way by either pests (birds, slugs, Diamondback moth (Plutella xylostella)) or diseases (White Blister Rust (Albugo candida) and Sclerotinia) as per the NR-trial. Mesurol (Methiocarb) pellets (insecticide) from Bayer was applied at 5.5 kg per hectare by hand to prevent slug and snail damage especially to lettuce.

Two pre-emergent herbicides were used. Dual Gold (960 g/L S-Metalochlor) was applied to broccoli by a tractor mounted boom spray at approximately 4 L per hectare either prior to or within one week of transplanting. This was then watered in for 1-2 hours with overhead sprinklers or by rain. Similarly Stomp 330E (330 g/L Pandemethalin) was applied prior to transplanting lettuce at approximately 4 L per hectare in a similar fashion.

For the first crop, a Hamilton tree-planter was used to hand plant 4,800 broccoli seedlings. For the remaining 3 crops a cup-transplanter was used to mechanically plant the broccoli and lettuce seedlings.

All four crops were affected in some way by either pests (birds, slugs, Diamondback moth, *Plutella xylostella*) or diseases White Blister Rust (*Albugo candida*) in part due to the drought in Victoria. Having a large and abundant supply of fresh water in the nearby dam attracted large flocks of birds which also attacked the crop, especially in the plots closest to the dam. This set some vegetables back 1-3 weeks. In more affected areas, some vegetables appeared to be roughly the same size at the end of the trial as they did at the start. Fortunately, only the outer leaves were nibbled in both lettuce trials, which left the hearts to grow on. After an attack, the lettuce seedlings were fertilised to help the plants to recover.

Mesurol 750 (750 g/kg Methiocarb) from Bayer was applied at 5.5 kg per hectare by hand to prevent slug and snail damage especially to lettuce. The insecticide was applied to both lettuce crops as they grew closer to the ground and were more likely to harbour pests such as slugs. Vegetable rows on the western side of the trial appeared to be more affected by slugs probably due to more shade imparted by the cypress trees in autumn and winter.

Ridomil Gold MZ (750/kg Mancozeb plus 40 g/kg Metalaxyl-M) was applied at 250 g/100 L water to prevent white blister and the biological insecticide, Delfin WG (850 g/L Bacillus thuringiensis) at 25 g/100 L water to control slugs. Sumisclex® 500 (fungicide) from Sumitomo was applied at 60 mL/60 L water to the first lettuce crop to prevent an outbreak of Sclerotinia during mid winter. The fungicide Ridomil Gold MZ (750/kg Mancozeb plus 40 g/kg Metalaxyl-M) was applied at 250 g/100 L water along with Nitrophoska (foliar fertiliser) to prevent white blister and Delfin WG (Delfin WG (850 g/L *Bacillus thuringiensis* - insecticide) at 25 g/100 L water to control Diamondback moth that both appeared later in the second broccoli crop.

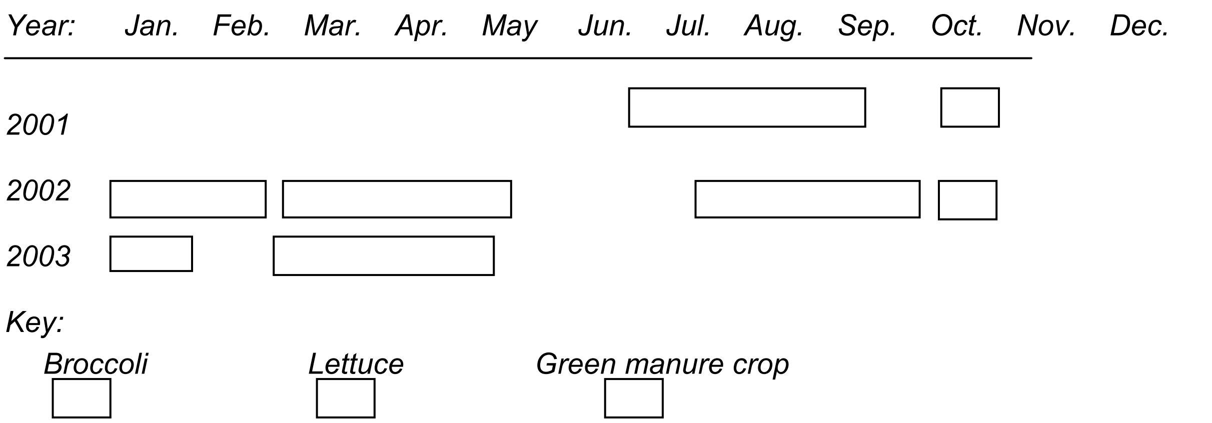
Three types of granular fertilisers (NPK) were used as either a basal application or side-dressings for both broccoli and lettuce. Nitrogen in the form of urea (46%), phosphorous as single superphosphate (8.8%) and potassium as potassium sulphate (41%) were all weighed out into small plastic containers in the laboratory. Approximately half of the fertiliser was applied down either row of vegetables within a plot. The fertilisers were applied either before rain or irrigation. Two different standard rates of nitrogen fertilisers were used for both trials (0, 40, 80, 120 and 160 kg/ha for broccoli and 0, 30, 60, 90 and 120 kg/ha for lettuce).

Crop sequence

Similarly to the NR-trial, 2 crops were planted each year over the 2 years (see Table 4.2). Broccoli was subsequently followed by a green manure crop that was followed by a lettuce crop as per the following sequence: Broccoli I – Green crop I - Lettuce I – Broccoli II – Green crop II - Lettuce II (Table 4.2).

The same variety of seedlings was used as per NR-trial for broccoli (Marathon) however two other varieties were used for lettuce (Legacy, Silverado).

Table 4.2. Planting sequence and timetable for vegetable growing period only



Dimensions of trial area

The trial consisted of 6 beds (one buffer bed) approximately 8 m in width and approximately 60 m in length which ran north-south. At each end several buffer plants were planted to help protect the end plots. The buffer row on the eastern side of the trial was next to vacant vegetable ground. Each row contained approximately 300 plants and in total 1,800 plants. Bed widths were approximately 0.9 m wide with 0.5-0.6 m furrows. The sown area of each plot measured 5.85 m^2 (6.5 m x 0.9 m).

Assessments

Compost analysis

To sample compost for analysis, a minimum of 6 litres was taken from the delivered composts, sealed in a snap-lock bag and stored in a cool dry place until delivery to the analytical laboratory (DPI Werribee). Composts were analysed according to AS4454.

Soil analysis

Soil samples from the top 0-10 cm were taken from designated plots with a hand spade within one week of final harvest. One to two scoops of soil was taken from three different positions along the middle of the plot and carefully placed in a snap lock bag, sealed and transferred to the 4ºC cool room within 45 minutes of sampling. It was then taken to the analytical laboratory (DPI Werribee) in an esky with ice for analysis within three days of sampling.

Yield at harvest

Both broccoli and lettuce heads were harvested into large plastic crates, weighed by bench scales and the number of heads per plot recorded in the field. The minimum standard was 'marketable' heads except in the second broccoli and lettuce trials. The second broccoli crop performed well but due to uncharacteristic warm weather later in the trial (especially at night) the crop did not form a tight compact head hence fresh weight samples only were recorded. Similarly, fresh weight samples were recorded in the second lettuce trial due to animal damage in some of the lower plots.

Soil physical measurements

A number of soil physical and chemical tests were performed. Tensiometers were installed in selected treatments just after transplanting for all 4 crops. An auger slightly larger than the diameter of the tensiometer was dug to a depth 5 cm below the ceramic tip of the tensiometer. A round wooden rod similar in diameter to the tensiometer was then driven another 5 cm into the ground with a mallet. The tensiometer was then fitted into the hole and carefully back-filled with soil. The soil was gently compacted with a metal rod and the surface immediately surrounding the tensiometer mounded a little, to prevent water running directly down the side of the tensiometer and giving a false reading. Measurements were recorded at two depths (15 cm and 30 cm) every 3-4 days in the morning for the life of the crop.

Soil bulk density was measured in the last 3 crops by taking core samples of known volume and mass. A corer with 3 metal rings 7.4 cm in diameter, two of 4.9 cm and one of 1 cm in length were placed in the corer. The corer was then driven into the ground the desired depth with a large metal weight. The corer was then removed and the soil from the middle ring carefully cut away with a fine spatular and placed onto a pre-weighed aluminium tray and dried in a 40ºC oven for a minimum of 48 hours. The dried soil was then re-weighed and recorded.

Ring infiltration was used to measure soil hydraulic conductivity after harvest for the last 2 crops. A relatively level soil surface was chosen and gently cleared of weeds and other obstructions (e.g. stones) and the ring placed in the desired location. Any vegetation or roots were trimmed around the outside of the ring and a piece of timber placed on top and gently hammered down 5 cm. The soil surrounding the ring was gently pushed back to ensure good contact and a small piece of hessian placed in the bottom. Water was slowly poured into the ring up to an 11 cm mark so as not to disturb the soil. The time taken for the water level to drop 10 cm was recorded by a stop-watch. The ring was then removed and cleaned ready for the next measurement. Two soil samples of approximately 1 cupful were taken, one outside the ring (initial soil moisture) and one inside the ring (saturated soil moisture) and placed on a pre-weighed aluminium tray. The soil samples were then dried in a 40ºC oven for a minimum of 48 hours. The dried soil was then re-weighed and used to calculate soil moisture and hydraulic conductivity.

Soil strength measurements were taken at field capacity with an RIMIK CP20 Cone Penetrometer for the last 3 crops. A stainless steel cone on the end of a shaft was inserted into the soil and pushed through at a steady rate. A sensor recorded the pressure needed to push the rod into the soil. Three measurements were taken in every plot each time and in the furrows of the last trial. The data was down-loaded on a PC and averaged for each plot.

Irrigation patterns were measured in the last broccoli and lettuce trials by placing one 5 L white ice-cream container in the middle of a plot and recording the amount of water collected from one hour of overhead irrigation. Volumes were measured by carefully tipping the water into a 250 mL measuring-cylinder and recording the data in the field. Irrigation volumes were recorded in all six blocks for broccoli and only 4 blocks for lettuce. The data was not analysed by itself but as a covariate to yield.

Similarly, soil moisture was calculated for all 9 treatments in 3 blocks to compare any differences within the last lettuce trial. Soil samples from the top 10 cm were taken with a hand spade at 3 different locations within a plot and placed on a pre-weighed aluminium tray and then dried in a 40ºC oven for a minimum of 48 hours (i.e. over the weekend). The dried soil samples were then re-weighed so that the soil moisture could be calculated (see Appendix X for soil moisture calculations).

Results

Broccoli 1

The effect of grease trap compost (GTC) and SGWC on average head weight of broccoli was not significant. However, average head weight was significantly higher in the SGWC treatment compared to GTC (Table 4.3). Poultry manure (PM) resulted in a significant increase in head weight compared to the control and GTC (Table 4.3). The effect of the green manure crop (GM) was not able to be determined as it had not yet been sown.

The analysis of the compost shows that the PM had much higher nutrient levels for N, ammonium, P, K, Ca and Mg compared to GT and SGW. The nitrogen content in PM provides an instant boost for plant growth as it is more readily available for plants. The SGW compost at both rates also resulted in a higher head weight than both the GT rates, but its effectiveness was reduced at the higher rate (Table 4.3).

Table 4.3. Effect of treatment on the average head weight of broccoli (Broccoli I, harvest November 2001)

Treatment	Average head weight (g)
C	202.2
PM(45/3)	221
GTC(45/3)	191
SGWC(45/3)	212.4
GTC(15)	202.1
SGWC(15)	214.2
GTC(GM)	196.7
SGWC(GM)	197.3
GM	211.7
lsd (5%)	16.8

Both SGWC and GTC showed signs of immaturity, having relatively high C:N ratios (especially GTC), very low NDI's, virtually no available N content and poor germination and toxicity test results (Table 4.4).

Table 4.4. Analysis of SGWC, GTC and poultry manure (PM) according to AS4454-1999 (Broccoli I, Systems Trial)

Analysis	Units	SGWC	GT	PM
Moisture @ 40ºC	% w/w	26	31	29
Moisture @ 105ºC	% w/w	44	39	39
pH-H_2O		8	6.2	7.2
Wetability	min	3.3	1.9	0.2
EC	dS/m	2.8	1.9	12.1
Na	mg/kg	1,300	2,000	4,000
Loss on Ignition (organic matter)	% w/w	55	81	75
C/N (Calc from Leco)		21	30	10
Total C	% w/w	27	45	34
N Drawdown 150 (NDI)		< 0.1	< 0.1	< 0.1
N	% w/w	1.3	1.5	3.4
NH_4-N	mg/L	< 5	11	820
NO_3-N	mg/L	< 5	< 5	< 5
P	mg/kg	2,200	1,900	19,000
K	mg/kg	8,800	1,900	15,000
S	mg/kg	1,400	1,400	4,000
Ca	mg/kg	19,000	14,000	28,000
Mg	mg/kg	4,000	1,000	5,300
Germination test	%	25	0	0
Toxicity test		20	0	0

Lettuce 1

Application of either compost at 15 m^3/ha or PM at 45 m^3/ha (added prior to the last crop, Broccoli 1) had no effect on the average head weight in the first lettuce crop (Table 4.5). However, the effects of SGWC applied at 45 m^3/ha prior to Broccoli 1 was still evident at harvest for this crop. This treatment resulted in an increase in head weight compared to the control (Table 4.4). On its own, the green manure crop (GM) also increased yield of lettuce, but not when used in combination with either compost. Though the compost-GM treatments did not affect yield compared to the control, a reduction in yield was observed between the GTC(GM) treatment and the GM crop on its own (Table 4.5).

Table 4.5. Effect of treatment on the average head weight of lettuce (Lettuce I, harvest July 2002)

Treatment	Average head weight (g)
C	185.1
PM(45/3)	210.1
GTC(45/3)	176.1
SGWC(45/3)	251.4
GTC(15)	153.5
SGWC(15)	211.1
GTC(GM)	177.5
SGWC(GM)	205.1
GM	228.2
lsd (p = 5%)	37.3

The GTC compost had a relatively high C:N ratio and lower NDI compared to SGWC (Table 4.6). This was probably the result of its high sawdust content (and consequently a high C content) that is used to counteract high moisture waste such as grease trap.

Table 4.6. Analysis of SGWC and GTC according to AS4454-1999 (Lettuce I, Systems Trial)

Analysis	Units	SGWC	GTC
Moisture @ 40ºC	% w/w	24	40
Moisture @ 105ºC	% w/w	27	42
pH-H_2O		7.6	6.1
Wetability	min	79	1
E.C.	dS/m	2.8	1.3
Na	mg/kg	1,500	1,600
Loss on Ignition (organic matter)	% w/w	40	78
C/N (Calc from Leco)		18	34
Total C	% w/w	21	44
N Drawdown 150 (NDI)		0.7	< 0.1
N	% w/w	1.2	1.3
NH_4-N	mg/L	34	47
NO_3-N	mg/L	< 5	< 5
P	mg/kg	1,800	1,700
K	mg/kg	9,800	2,600
S	mg/kg	1,500	1,300
Ca	mg/kg	22,000	13,000
Mg	mg/kg	5,200	1,100
Germination test	%	45	60
Toxicity test		48	43

Broccoli 2

There were no significant differences between the treatments for both compost type and compost rate (Table 4.7). This may be because the higher compost rate (45 m^3/ha) was applied 2 crops earlier (before broccoli I) and therefore had very little residual effect. Similarly, no poultry manure was added prior to this crop so its effect was reduced. On a trend basis, the crop responded better to the SGWC than the grease trap (GT) compost, especially when it was applied in smaller doses just before planting (15 m^3/ha) than at the higher rate once annually.

Table 4.7. Effect of treatment on the average head weight of broccoli (Broccoli II, harvest December 2002)

Treatment	Average head weight (g)
C	276.3
PM(45/3)	316.8
GTC(45/3)	328.2
SGWC(45/3)	298
GTC(15)	313.4
SGWC(15)	325.2
GTC(GM)	290.2
SGWC(GM)	351.3
GM	346
lsd (5%)	71.1

The composts used in this trial exhibited hydrophobic tendencies (high wetability results), had low NDI's and comparatively low (compared to other samples of the same composts) total N contents (Table 4.8).

Table 4.8. Analysis of SGWC and GTC according to AS4454-1999 (Broccoli II, Systems Trial)

Analysis	Units	SGWC	GTC
Moisture @ 40ºC	% w/w	19	40
Moisture @ 105ºC	% w/w	22	43
pH-H_2O		7.5	5.6
Wetability	min	20	53
E.C.	dS/m	4.2	2.1
Na	mg/kg	1,500	1,500
Loss on Ignition (organic matter)	% w/w	40	84
C/N (Calc from Leco)		17	41
Total C	% w/w	20	49
N Drawdown 150 (NDI)		0.2	< 0.1
N	% w/w	1.2	1.2
NH_4-N	mg/L	33	56
NO_3-N	mg/L	1.1	< 5
P	mg/kg	2,100	1,700
K	mg/kg	9,500	1,600
S	mg/kg	1,500	1,400
Ca	mg/kg	17,000	9,300
Mg	mg/kg	5,700	750
Germination test	%	15	15
Toxicity test		2	33

The GTC compost in particular had a high C:N ratio (41), and germination and toxicity tests were poor for both composts (Table 4.8).

Lettuce 2

There was no significant differences between the treatments for average head weight of lettuce in June 2003 (Table 4.9).

Table 4.9. Effect of treatment on the average head weight of lettuce (Lettuce II, harvest June 2003)

Treatment	Average head weight (g)
C	352.6
PM(45/3)	415.7
GTC(45/3)	427.8
SGWC(45/3)	395.6
GTC(15)	310.8
SGWC(15)	370.6
GTC(GM)	375.2
SGWC(GM)	434
GM	340.1
lsd (5%)	252.1

While the C:N ratio of the GTC compost that was used in the previous systems trial was 41 (Table 4.8), the same product used in this trial had a C:N ratio of 19 (Table 4.10). In addition, this compost had a comparatively high ammonium-N content, but like most composts used in these trials, nitrate-N levels were very low (Table 4.10). As a result of this, the GTC and SGWC products had low NDI test results. Despite the fact that PM had a relatively high total N and ammonium-N content, its NDI was also very low (Table 4.10).

Table 4.10. Analysis of SGWC, GTC and poultry manure (PM) according to AS4454-1999 (Lettuce II, Systems Trial)

Analysis	Units	SGWC	GTC	PM
Moisture @ 40ºC	% w/w	30	33	29
Moisture @ 105ºC	% w/w	36	42	37
pH-H_2O		7.9	6.3	6.7
Wetability	min	1.6	0.5	0.5
E.C.	dS/m	4.3	4.2	6.7
Na	mg/kg	2,400	2,400	3,900
Loss on Ignition (organic matter)	% w/w	38	83	80
C/N (Calc from Leco)		15	19	10
Total C	% w/w	20	40	33
N Drawdown 150 (NDI)		0.2	< 0.1	< 0.1
N	% w/w	1.3	2.1	3.2
NH_4-N	mg/L	51	290	420
NO_3-N	mg/L	< 5	< 5	< 5
P	mg/kg	1,900	7,500	18,000
K	mg/kg	9,200	6,700	14,000
S	mg/kg	1,100	2,600	4,000
Ca	mg/kg	17,000	21,000	30,000
Mg	mg/kg	3,700	2,400	5,700
Germination test	%	95	95	100
Toxicity test		50	75	8

Effects of treatments on soil physics and chemistry

In the second broccoli crop, tensiometers were installed to measure soil moisture at two depths (15 cm and 30 cm) to compare the effects of GT compost application with and without any additional green manure (GM) crop. Tensiometers were generally read twice per week over the trial period. The combination of compost and GM provided the highest soil moisture levels at both the measured depths (Figure 4.1). In addition, the GM crop appeared to be contributing more to higher soil moisture levels than the compost. This might be because the compost was incorporated much earlier on than the GM. This data shows that the effects of compost and GM on soil conditions were still observed many months after incorporation (at least 14 months after application of compost and 6 months after incorporation of the GM).

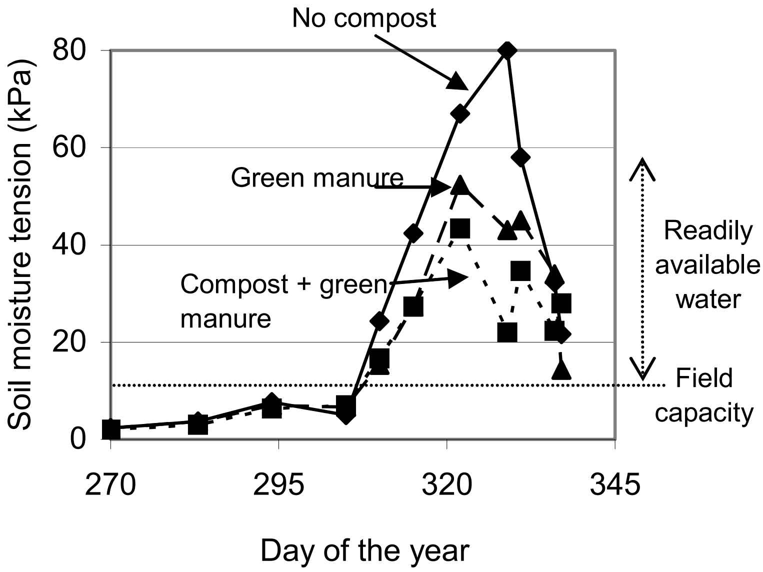


Figure 4.1. The effect of green manure and a green manure plus compost t.

Treatment (GTC data shown) on soil moisture tension (Broccoli II, Systems Trial).

Table 4.11. Effect of treatment at various depths on the average soil strength following harvest of broccoli (Broccoli II, harvest December 2002)

Depth (mm)	Soil strength (KPa)									*lsd (5%)*
	C	PM (45/3)	GTC (45/3)	SGWC (45/3)	GTC (15)	SGWC (15)	GTC (GM)	SGWC (GM)	GM	
25	541	484	488	488	463	414	438	488	430	169.4
50	850	723	684	684	792	698	683	708	711	274.2
75	1108	942	869	873	1037	956	957	892	977	339.1
100	1584	1162	1257	1134	1328	1176	1170	1091	1282	489.4
125	1924	1401	1698	1397	1848	1483	1524	1341	1660	632.9
150	2126	1597	1894	1772	2170	1799	1847	1608	1956	720.6
175	2441	1644	1915	2020	2301	2067	1987	1798	2272	766.2
200	2761	1973	2232	2317	2430	2183	2304	2029	2566	742.1
225	3037	2444	2518	2239	2788	2578	2737	2342	2878	755.1
250	3144	2545	2728	2400	2888	2847	2865	2406	3038	682.2
275	3151	2561	2697	2599	3059	3004	3054	2266	3234	716.5
300	3072	2393	2702	2614	2870	3024	3246	2011	2856	671.4

Soil penetrometer results taken in December 2002 are shown in Table 4.11. There was no significant differences in soil strength between treatments at 25, 50, 75, 125 and 150 mm. At 100 mm (approximately the depth of compost incorporation), soil strength was reduced by the SGWC(GM) treatment combination (Table 4.11). Reduced soil strength in the amended soil could effectively result in increased soil depth (Figure 4.2). At depths greater than 150 mm, the compost treatments reduced soil strength, but at these depths, the penetrometer readings were above the limit usually believed to restrict root growth (above 1500 kPa) (Table 4.11).

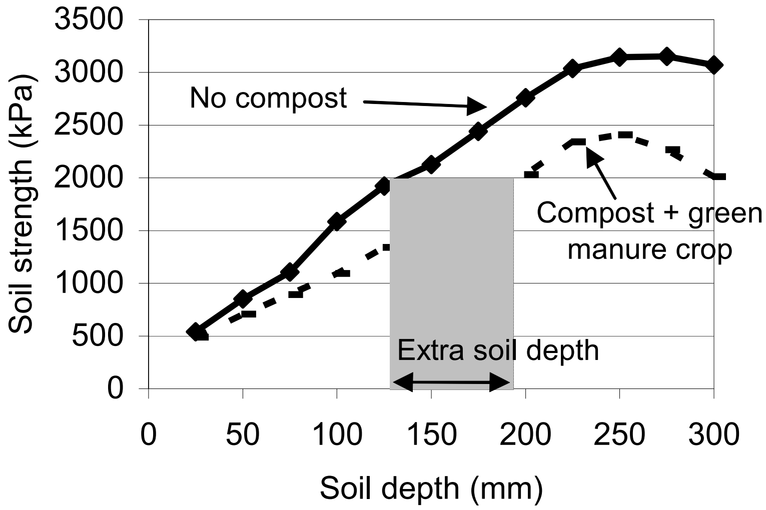


Figure 4.2 Effect of green manure crop plus SGWC compost and depth on soil strength.

Soil strength readings were also taken at harvest after the second lettuce crop. These showed similar trends to treatment effects as that observed in the previous crop. The beneficial effects of treatments were mainly seen at depths greater than 200 mm (Table 4.12), effectively resulting in an increase in soil depth (Figure 4.2).

Table 4.12. Effect of treatment at various depths on the average soil strength following harvest of lettuce (Lettuce II, harvest June 2003)

Depth (mm)	Soil strength (KPa)									*lsd (P 5%)*
	C	PM (45/3)	GTC (45/3)	SGWC (45/3)	GTC (15)	SGWC (15)	GTC (GM)	SGWC (GM)	GM	
25	155	247	341	178	321	196	204	209	177	57.2
50	191	260	349	269	361	236	221	247	204	66.6
75	299	347	375	400	480	343	273	296	299	94.0
100	564	527	498	575	700	492	421	452	492	148.4
125	895	751	782	927	984	678	741	729	856	256.0
150	1092	935	1005	1284	1262	875	1000	975	1090	338.4
175	1267	1169	1104	1396	1332	1115	1074	1076	1191	375.2
200	1517	1226	1248	1461	1411	1330	1198	1279	1388	426.1
225	1818	1425	1561	1534	1749	1391	1605	1497	1583	468.2
250	2065	1715	1711	1877	2277	1651	1833	1663	1762	403.5
275	2081	2083	1823	2110	2423	1939	2048	1753	2140	459.7
300	2129	2142	1890	2224	2404	2035	1944	1758	2269	433.3

Hydraulic conductivity tests were also conducted on treatment plots after Broccoli II harvest (December 2002). Despite high variation in the observed measurements, the control treatment had a significantly higher rate of infiltration (cm/sec) than the PM, SGWC(45/3) and the SGWC(15) treatments (data not shown).

Consistent trends in changes to soil chemistry as a result of the treatments were not observed until the fourth successive lettuce crop (Figures 4.3-4.6; Table 4.13). After the fourth vegetable crop, the SGWC(GM) treatment combination appeared to result in the largest improvements to soil chemistry. Little observable differences could be detected with the GM treatment alone, and the GTC(GM) treatment effects were smaller than the SGWC(GM) treatment (Figures 4.3-4.6; Table 4.13).

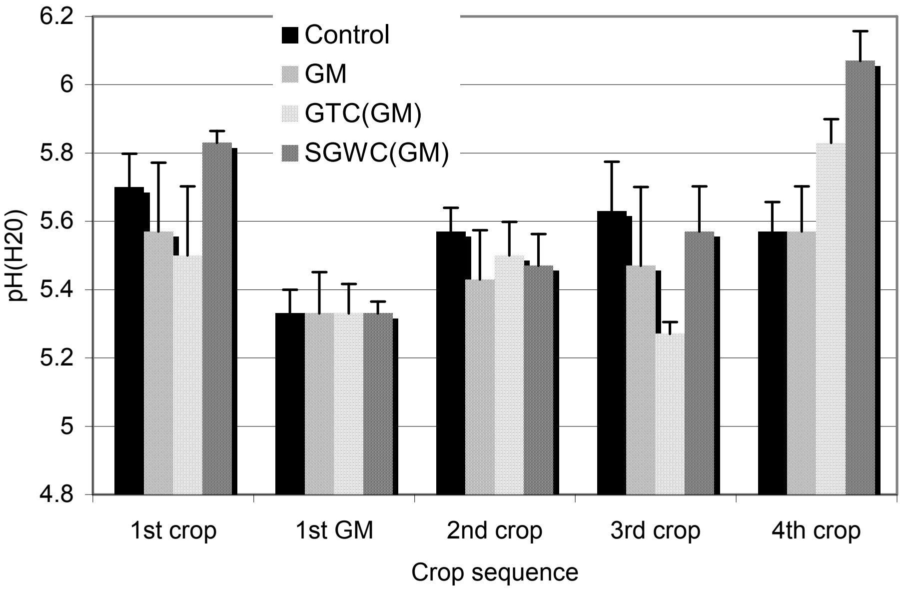


Figure 4.3. Effect of soil amendment (composts and green manure crops) on soil pH over four successive vegetable crops. 1st GM – results of soil samples taken after incorporation of first GM crop.

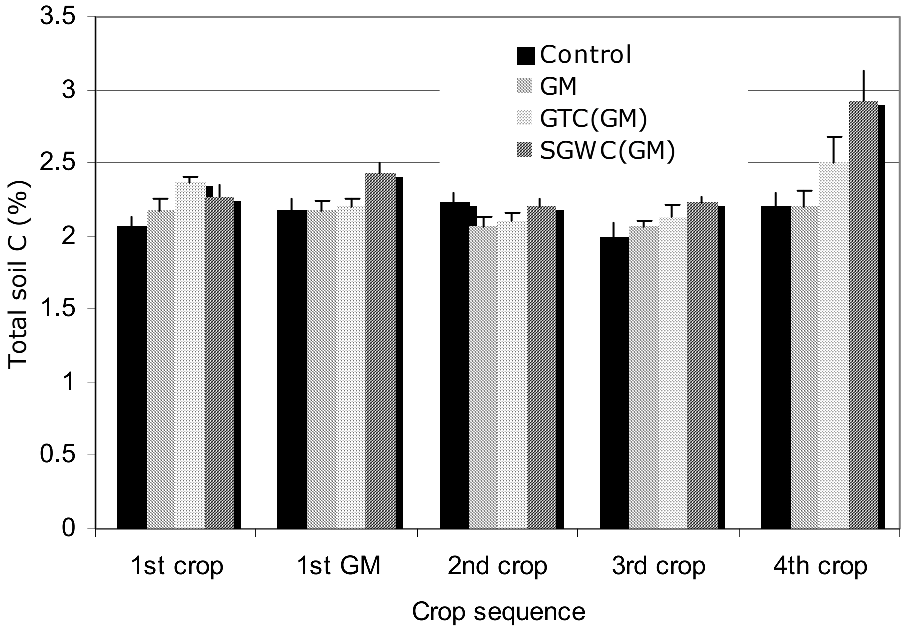


Figure 4.4. Effect of soil amendment (composts and green manure crops) on total soil C over four successive vegetable crops. 1st GM – results of soil samples taken after incorporation of first GM crop.

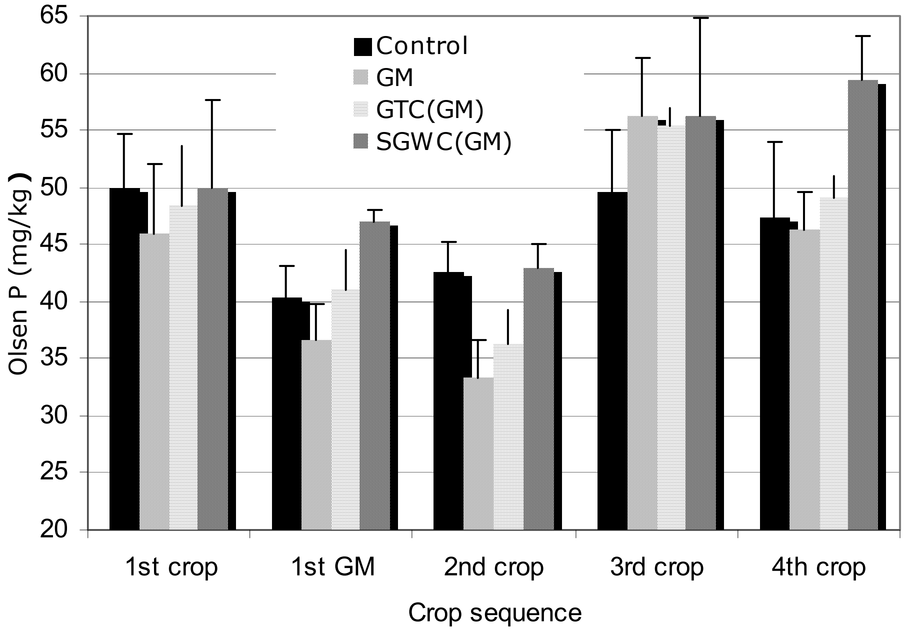


Figure 4.5. Effect of soil amendment (composts and green manure crops) on Olsen P over four successive vegetable crops. 1st GM – results of soil samples taken after incorporation of first GM crop.

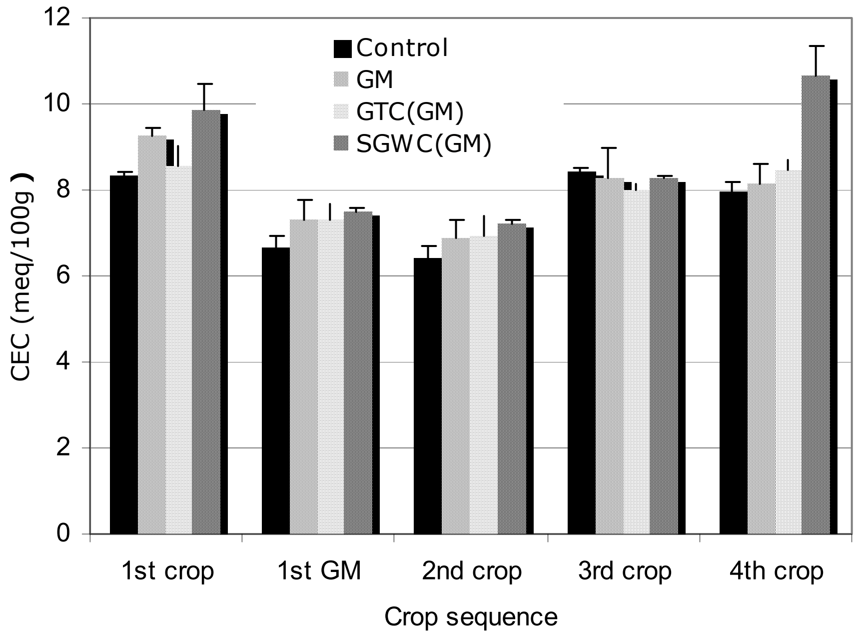


Figure 4.6. Effect of soil amendment (composts and green manure crops) on CEC over four successive vegetable crops. 1st GM – results of soil samples taken after incorporation of first GM crop.

Table 4.13. Changes to soil chemistry following application of treatments in the Systems Trial. Data are means and SD's of 3 samples

Analyte	Units	Control										GM									
		1st crop		1st GM		2nd Crop		3rd Crop		4th Crop		1st crop		1st GM		2nd Crop		3rd Crop		4th Crop	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
pH H_20		5.7	0.17	5.33	0.12	5.57	0.12	5.63	0.25	5.57	0.15	5.57	0.35	5.33	0.21	5.43	0.25	5.47	0.4	5.57	0.23
EC	dS/m	0.17	0.04	0.12	0.01	0.09	0.01	0.18	0.02	0.16	0.02	0.15	0.05	0.12	0.02	0.09	0.01	0.21	0.03	0.17	0.05
TSS	% w/w	0.06	0.01	0.04	0	0.03	0	0.06	0.01	0.05	0.01	0.05	0.02	0.04	0.01	0.03	0	0.07	0.01	0.05	0.02
Total C	% w/w	2.07	0.12	2.17	0.15	2.23	0.12	2	0.17	2.2	0.17	2.17	0.15	2.17	0.12	2.07	0.12	2.07	0.06	2.2	0.2
Total N	% w/w	0.15	0.01	0.15	0.01	0.16	0.01	0.15	0.01	0.15	0.01	0.16	0.01	0.15	0.01	0.15	0	0.15	0.01	0.14	0.01
Olsen P	mg/kg	50	8.19	40.3	4.73	42.7	4.51	49.7	9.24	47.3	11.6	46	10.5	36.7	5.51	33.3	5.86	56.3	8.5	46.3	5.51
CPC S	mg/kg	67.3	22.4	30.3	3.06	36	4	53.7	17	52	18.1	66.3	29.4	34.7	4.04	34.7	4.93	64	24.3	49	7.55
Exch Ca	meq/100 g	6.9	0.1	5.03	0.42	4.97	0.47	6.53	0.32	6.3	0.26	7.6	0.2	5.57	0.67	5.27	0.65	6.37	0.95	6.4	0.66
Exch Mg	meq/100 g	1.11	0.19	1.08	0.13	1.01	0.09	1.27	0.15	1.23	0.15	1.3	0.17	1.23	0.12	1.17	0.15	1.27	0.21	1.23	0.15
Exch Na	meq/100 g	0.1	0.01	0.15	0.01	0.12	0.01	0.19	0.01	0.16	0.02	0.13	0.03	0.18	0.02	0.13	0.02	0.14	0	0.17	0.04
Exch K	meq/100 g	0.2	0.03	0.31	0.04	0.29	0.04	0.38	0.04	0.27	0.07	0.22	0.04	0.31	0	0.25	0.04	0.45	0.06	0.3	0.02
CEC	meq/100 g	8.33	0.15	6.63	0.55	6.4	0.53	8.4	0.2	7.97	0.4	9.27	0.32	7.3	0.78	6.87	0.75	8.3	1.15	8.13	0.8
Ca:Mg	% w/w	6.37	1.16	4.7	0.26	4.97	0.35	5.27	0.91	5.2	0.4	5.97	0.72	4.57	0.15	4.57	0.06	5.07	0.29	5.23	0.25
Ca	% w/w	83.7	2.08	77	1	78	1	78.3	2.31	79.7	1.15	82.7	1.53	76.7	0.58	77.7	0.58	77.7	1.53	79.3	0.58
Mg	% w/w	14	2	16.7	0.58	16	1	15.3	2.08	16	1	14.3	1.15	17.3	0.58	17.7	0.58	15.7	0.58	15.7	0.58
Na	% w/w	1.67	0.58	3	0	2	0	3	0	2.33	0.58	1.67	0.58	3	0	2.33	0.58	2	0	2.33	0.58
K	% w/w	3	0	5	1	5	1	4.67	0.58	4	1	2.67	0.58	4.33	0.58	4	1	5.67	1.15	4.33	0.58
pH H_20		5.5	0.35	5.33	0.15	5.5	0.17	5.27	0.06	5.83	0.12	5.83	0.06	5.33	0.06	5.47	0.16	5.57	0.23	6.07	0.15
EC	dS/m	0.15	0.05	0.12	0.01	0.07	0.01	0.22	0.03	0.13	0.03	0.15	0.05	0.13	0.02	0.09	0.01	0.16	0.09	0.2	0.06
TSS	% w/w	0.05	0.01	0.04	0	0.03	0.01	0.07	0.01	0.04	0.01	0.05	0.02	0.04	0.01	0.03	0	0.05	0.02	0.07	0.02

Table 4.13 continued …

Analyte	Units	GTC(GM)										SGW(GM)									
		1st crop		1st GM		2nd Crop		3rd Crop		4th Crop		1st crop		1st GM		2nd Crop		3rd Crop		4th Crop	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total C	% w/w	2.37	0.06	2.2	0.1	2.1	0.1	2.13	0.15	2.5	0.3	2.27	0.15	2.43	0.12	2.2	0.1	2.23	0.06	2.93	0.35
Total N	% w/w	0.16	0	0.15	0	0.15	0	0.15	0	0.15	0	0.16	0.02	0.16	0.01	0.15	0.01	0.15	0.01	0.2	0.02
Olsen P	mg/kg	48.3	9.07	41	6	36.3	5.13	55.3	2.89	49	3.46	50	13.1	47	1.73	43	3.46	56.3	14.8	59.3	6.81
CPC S	mg/kg	58.7	27.8	40.3	5.51	26	4.58	81.7	26	35.7	10.6	45.7	20.2	41	3	35	9.85	47	30.1	49	17.4
Exch Ca	meq/100 g	6.93	0.86	5.53	0.59	5.3	0.62	6.2	0.2	6.67	0.31	8.07	0.76	5.7	0.17	5.57	0.12	6.33	0.06	8.03	0.42
Exch Mg	meq/100 g	1.2	0	1.23	0.06	1.17	0.15	1.17	0.06	1.3	0.1	1.3	0.1	1.2	0	1.17	0.06	1.27	0.12	1.7	0.17
Exch Na	Meq/100 g	0.15	0.02	0.19	0	0.14	0.02	0.15	0.02	0.19	0.01	0.13	0.03	0.19	0.01	0.14	0.01	0.15	0.01	0.36	0.1
Exch K	Meq/100 g	0.23	0.03	0.31	0.02	0.28	0.06	0.43	0.05	0.27	0.03	0.25	0.08	0.32	0.03	0.29	0.01	0.45	0.15	0.61	0.1
CEC	meq/100 g	8.57	0.81	7.3	0.61	6.93	0.81	8	0.26	8.47	0.4	9.87	1.03	7.47	0.23	7.23	0.15	8.27	0.06	10.7	1.15
Ca:Mg	% w/w	5.83	0.76	4.53	0.25	4.6	0.26	5.37	0.35	5.17	0.21	6.23	0.15	4.8	0.17	4.8	0.2	5.07	0.49	4.8	0.26
Ca	% w/w	81.7	2.52	76.3	1.53	77.3	1.15	78.3	0.58	79.3	0.58	83	0	77.3	0.58	78	1	77.7	0.58	75.3	1.15
Mg	% w/w	14.3	1.53	17.7	0.58	17.3	0.58	15	1	15.7	0.58	13.7	0.58	16.3	0.58	16.7	0.58	16	1.73	16.3	0.58
Na	% w/w	2	0	3	0	2.33	0.58	2.33	0.58	3	0	2	0	3	0	2.33	0.58	2	0	4	1
K	% w/w	3.33	0.58	4.67	0.58	4.33	0.58	5.67	0.58	3.67	0.58	3	1	4.67	0.58	4.33	0.58	5.67	1.53	5.67	0.58

Discussion

These results have shown improvements in soil physical and chemical conditions following the use of composted soil amendments, sometimes in combination with a green manure crop. As per the N-replacement trials in Victoria, these improvements did not result in consistent increases in crop productivity because crop growth was often compromised by poor compost quality, weeds and diseases and bird damage.

Though consistent results were not obtained, there were some indications that a combination of green manure crops and compost could be beneficial on heavy soils in Victoria. Whilst a green manure adds bulk organic matter to soil and some nutrients (especially from N fixation by legumes in the mix), the compost is a source of more stabilised organic matter. Thus, the addition of labile organic matter, such as that contained in a green manure stimulates soil microbiological activity, which is important for nutrient cycling and the physical stabilisation of soil (Sela *et al*. 1998; Kuzyakov *et al*. 2000; Tisdall 1994). Improvements to soil physical conditions were seen in some of these trials following the incorporation of a green manure. In fact, in one case, the effects of compost and GM on soil conditions were still observed many months after incorporation (at least 14 months after application of compost and 6 months after incorporation of the GM).

Consistent with our findings in the N-replacement trials in Victoria, the quality of the composts used was often not good enough for vegetable production. It was evident that when the compost was of reasonable quality, the best results were obtained with the compost/green manure combination. However, when compost quality was seriously compromised, as was with the case often with the grease trap (GT) compost, the compost had potentially negative effects on its own and reduced the advantage of incorporating the green manure.

Of all the composts used in the Victorian trials, the GT compost was the most variable in quality. This is most likely the result of variations in the amount of sawdust used to absorb the high moisture content grease trap waste. In 4 tests of this compost, wetability (a measure of the hydrophobicity of compost) varied from 0.5 to 53 minutes, C:N from 19 to 41, total N from 1.2 and 2.1 per cent w/w and total K content varied from 1900 to 6700 mg/kg. However, previous work with this compost has shown that improvements to crop growth can be expected if the compost quality is satisfactory (Wilkinson 1999). Grease trap compost is known to be particularly phytotoxic unless it is adequately matured (Beardsell, pers. comm.). In addition, results observed in these trials also suggest that the immature GT compost could also compete with crops for available N.

SECTION 5 COMMERCIAL DEMONSTRATION SITES

Introduction

The establishment of a number of commercial grower sites where the use of compost and the incorporation of results from the research station trial programs could be commercially tested was not as successful as anticipated.

Previous works has been carried out on a number of grower properties; however, request to establish permanent sites for up to two years and possible requirements to change some management practices did not attract any volunteers. Further only one of the two growers that we had previously conducted some continuous trials and demonstrations with, was in a position to continue supporting the work. Possibilities of developing sites in newer growing regions at Gingin were not pursued because of the travel time involved.

We were able to establish two sites on the one property at Baldivis and they will be referred to as Site 1 and Site 2:

- Site 1 was located at the northern end of the property and to the east of where we had conducted previous work.
- Site 2 was established almost 9 months later at the southern end of the property.

Soil types are commonly described as Karakatta sands. They represent the dominant type of the two most important sandy soils of the Swan Coastal Plain and are included within the Spearwood soil-landscape system. This system is described as 'Sand dunes and plains on Aeolian sand and limestone over sedimentary rocks' in the Western Swan Coastal Plain from Dunsborough to Jurien. Yellow deep sands, pale deep sands and yellow/brown shallow sands dominate and vegetation ranges from Tuart-Marri forest and woodland in south to heath and open woodland in north.

By physical description they are coarse sand as are virtually all of the sandy soils found on the coastal plain. They comprise over 90 per cent coarse sand with only trace amounts of silt and usually have less than 2 per cent clay content.

The farm has been in continuous vegetable production for more than 25 years and crop rotation has largely involved onions, potato, carrots and cauliflower. Onions have not been planted in recent years.

Permanent irrigation utilise Martin impact sprinklers that are spaces 12 m apart in rows that are 14 m apart.

The area defined between sprinkler rows is referred to as a 'Bay' and within each bay, 9 beds are formed up prior to establishing crops such as carrots (sown in three double rows) and cauliflowers (planted in two rows per bed). With potatoes, the seed is planted in double furrows that constitute a bed. The width of each bed is 1.5 m.

Sprinkler uniformity was tested in 1996 in the adjacent area that was previously used by the Department of Agriculture. Because the sprinkler lines are 14 m rather than 12 m apart, uniformity is affected, however it is acceptable along the rows and within the middle regions of each bay.

Materials and methods – SITE 1

Site detail

The site is to the east of the initial vegetable compost work that with funding by the WA Department of Agriculture in 1996/97. This work was extended with 12 month Vegetable industry/HRDC (now Horticulture Australia Ltd - HAL) funding through the project VC 97079, 'Soil amendments to improve vegetable production on sandy soils' (Paulin *et al*. 1999).

Following on from this, the grower in cooperation with a compost producer that had been involved with the Department's work, established an area to monitor long term benefits of regular compost use on their vegetable production.

Treatments

The site was established in March 2002 to the east of an area already established by the grower utilising a compost derived form predominantly agricultural feedstocks (Compost-R). The crop sequence is provided in Table 5.1 and the layout is provided in Figure 5.1. Treatment block were a single bay (14 m) by the length of the planting area that varied from 235 m to 258 m.

The site offered an opportunity to include compost made from predominantly agricultural feedstocks (Compost-R) with the product made from predominantly urban green wastes (Compost-U) that was from the same source as the compost used in program at the Medina Research Station. The main difference between the two composts being the larger proportion of lignified woody materials used in Compost-U.

The grower established compost evaluation area to the east of the untreated control bay, had received 8 applications of Compost-R (and Compost-R1) in Figure 5.1 and the area to the west had received only three applications of the same compost. Compost-U was applied to a bay the had received one application of Compost-R and the untreated control was set up to the west as shown in Figure 5.1.

Rates (20 m^3/ha/crop) and application methods were identical for both composts and application varied according to the crop. No variations were made to the growers fertiliser programs.

Compost was either placed in a narrow band with potatoes and cauliflowers or spread on top of the formed bed prior to sowing carrots. With carrots and cauliflowers, crop establishment was usually immediately after compost application and always within 2 to 3 days. With potatoes, compost was applied within the natural ridges left by the planter, around 14 days after planting.

Because of the nature of the planting program, it was not always possible to plant both compost areas at the same time; however it was always possible to ensure that each compost treatment was established at the same time as its adjacent control plot.

Table 5.1. Cropping sequence at Compost demonstration Site 1

Crop	Date of			Notes
	Compost applic^n.	Crop establishment	Harvest	
Carrot	4 March 2002	6 March 2002	17 July 2002	Compost-R variety Stefano.
Cauliflower	Late August 2002	E September 2002	26 & 28 November 2002	Two harvests and club root assessment.
Carrot	8 January 2003	9 May 2003	14 May 2003	Compost-R variety Stefano.
	15 January 2003	9 May 2003	19 May 2003	Compost-U variety Stefano.
Potato	Late May 2003	Mid-June	9 October 2003	Compost-R variety. Mondial. Bin harvest.
	E June 2003	Late June	9 October 2003	Compost-U variety. Royal Blue. Bin harvested.
Carrot	Mid-December 2003	Mid-December	8 April 2004	Bin harvested.

Soil quality

The four treatment blocks were soil sampled in early March 2002. The analysis included, phosphorus, potassium. pH, Soil carbon, and electrical conductivity. Subsequently soils were tested in late May 2003 and after the fifth and final crop on 23 April 2004. Thirty sub samples were collected per plot from 0 to 10 cm and 30 to 45 cm soil depth.

Crop performance

Crop performance was assessed by harvesting 10 sub plots per treatment and or by recording the commercial harvest. For carrots; 10, 2 m section from the central double row was harvested and washed prior to assessment; for cauliflower, 8, 3 m double row sub plots comprising 20 plants were harvested and with potatoes, only commercial harvests were recorded.

To facilitate comparison between treatments with commercial harvests, the areas for each treatment bay was provided by the grower as per the layout diagram, Figure 5.1.

Quality was assessed in accordance with commercial practice and included total and marketable harvest weights and a breakdown of defects that are of importance to the crop. All sub-plot data was recorded systematically so that trends along the treatment bays could be assessed.

Crop varieties throughout the cropping program were Stefano carrots, Freemont cauliflower and both Mondail and Royal Blue potatoes.

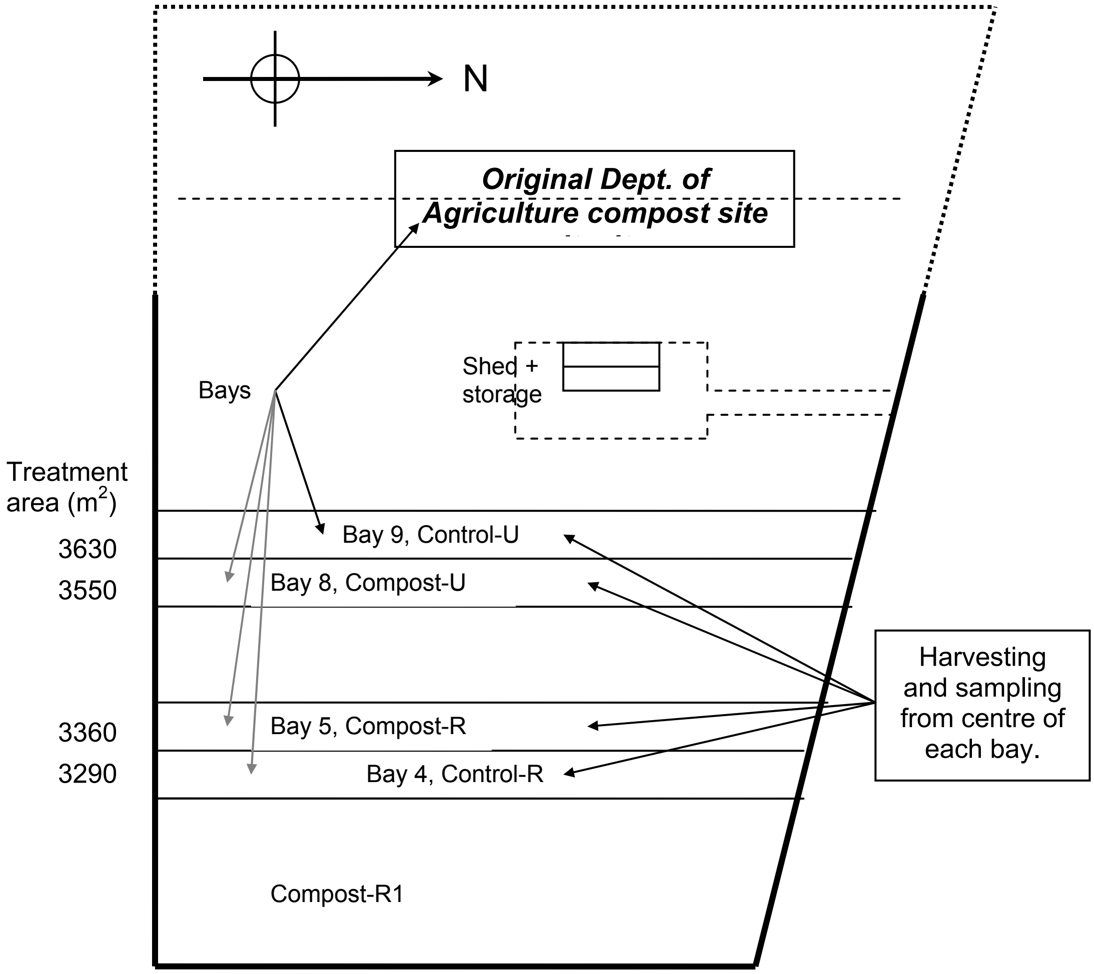


Figure 5.1. Commercial compost use demonstration Site 1 (NOT to scale).

Irrigation monitoring

Opportunity was taken to monitor potential impact of compost on soil moisture using the already established demonstration site utilising Compost-R. This was prior to commencing the application of Compost-U later in 2002.

The cauliflower seedlings were planted on the 20 December 2001 and the recording of irrigation and soil moisture commenced at this time.

Materials and methods – SITE 2

The second Commercial compost demonstration site was established towards the southern end of the same property in Late November 2002. This area of the property was developed around 12 months later that the northern part, otherwise soils, irrigation and crop rotations are the same as for Site 1.

Treatments

Compost-R and Compost-U were again used and two replicates along with control blocks laid out as shown in Figure 5.2.

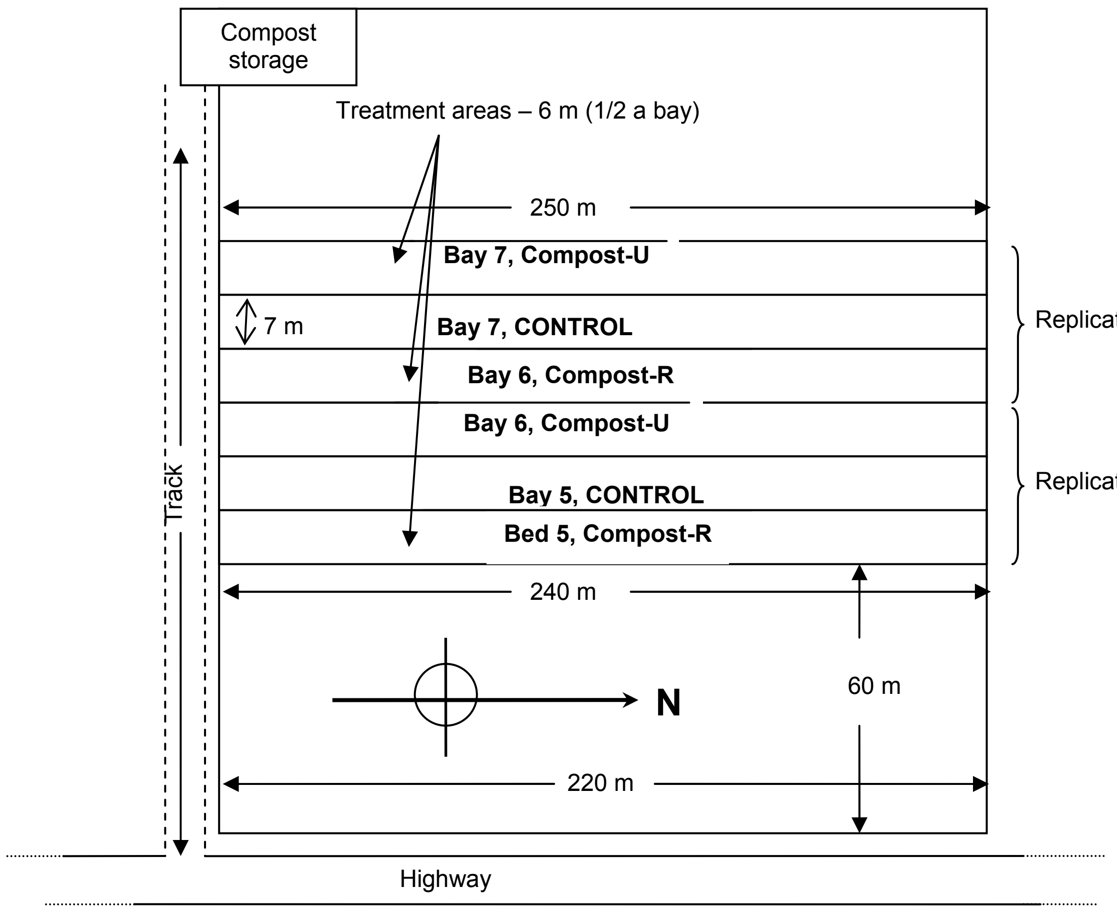


Figure 5.2. Commercial compost demonstration Site 2 layout (NOT to scale).

The crop sequence is provided in Table 5.2 and the layout is provided in Figure 5.2. Treatment block were a single bay by the length of the planting area that varied from 235 m to 258 m.

Rates (20 m^3/ha/crop), varieties and application methods were also the same as used in Site 1 and again, no variations were made to fertiliser programs.

Table 5.2. Cropping sequence at Compost demonstration Site 2

Crop	Date of			Notes
	Compost applic^n.	Crop establishment	Harvest	
Cauliflower	Late November 2002	Late November 2002	3-15 February 2003	Five harvests
Carrot	Late March 2003	Late March 2003	Early September 2003	
Cauliflower	Late August 2002	E September 2002	18 December 2003	Severe Diamondback Moth

Results

SITE 1

Soil analysis

Results of soil sampling conducted prior to establishing Demonstration Site 1, in May 2003 and in April and after the completion of the final crop in April 2004 are provided in Table 5.3. Analysis was conducted by the Chemistry Centre in Perth WA.

Table 5.3. Soil analysis values prior to first crop and after the last crop at the Compost demonstration Site 1

Analyte	Unit	Control-R			Compost-R			Control-U			Compost-U		
		Mar-02	May-03	Apr-04	Mar-02	May-03	Apr-04	Mar-02	May-03	Apr-04	Mar-02	May-03	Apr-04
Organic Carbon	% (W/B)	0.56	0.56	0.52	0.78	0.86	0.88		0.62	0.56	0.59	0.82	0.74
pH	($CaCl_2$)	6.9	7.4	7.6	6.9	7.3	7.5		7.5	7.8	7.0	7.5	7.7
EC	(1:5) mS/m	14	7	8	15	8	11		8	9	13	8	9
N total	%	0.026	0.03	0.026	0.044	0.06	0.054		0.04	0.03	0.029	0.06	0.049
P total	mg/kg		110	140		150	250		120	180		160	290
P (HCO3)	mg/kg	58	58	47	80	69	60		67	65	71	68	78
K total	mg/kg		29			32			26			28	
K (HCO3)	mg/kg	31	28	33	41	34	44		25	37	33	24	46
Ca	mg/kg-me%		1100	2.04		1200	2.73		1100	2.55		1500	2.87
Mg	mg/kg-me%		78	0.37		92	0.51		84	0.43		100	0.51

Compost quality

With one exception all composts used at Demonstration Site 1 were analysed for a standard range of measurements in accordance with the Australian standards for Composts, Soil Conditioners and Mulches, AS 4454-2003. A summary of the results are provided in Table 5.4 and individual compost values are provided in Appendix 5.1.

Irrigation

Crop factors provided in Table 5.5 express the amount of irrigation plus rainfall as a percentage of the Standard pan (E pan) evaporation recorded at the near by Medina Research Station. This shows that the crop received 746 mm of rainfall/irrigation against evaporation of 519.1 mm. Giving an overall crop factor of 144 per cent.

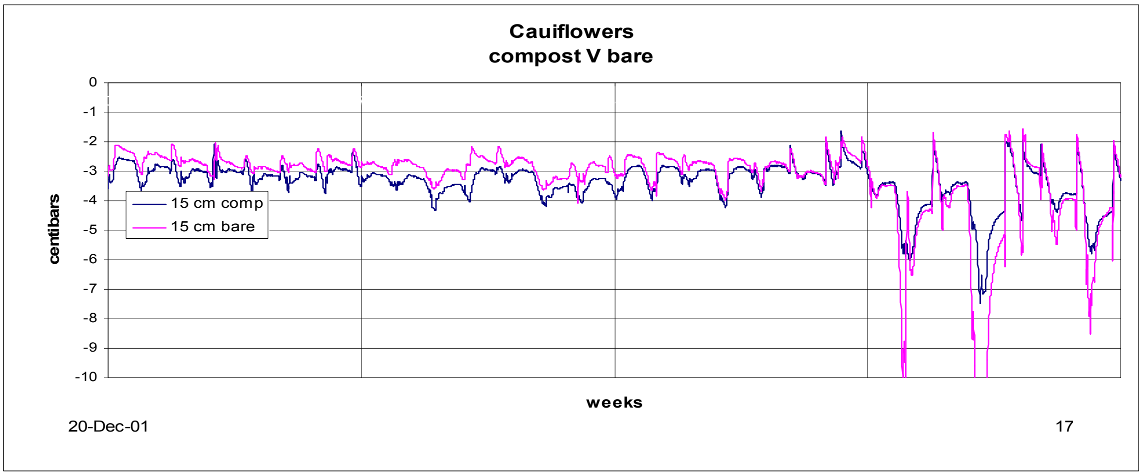
Soil moisture data recorded from the tensiometers is graphed at each of the three depths and compares compost treated and adjacent untreated areas of crop. The vertical lines indicate weeks and each graph provides four weeks of data. Figures 5.3 and 5.4 therefore provide soil moisture data over two consecutive four week periods.

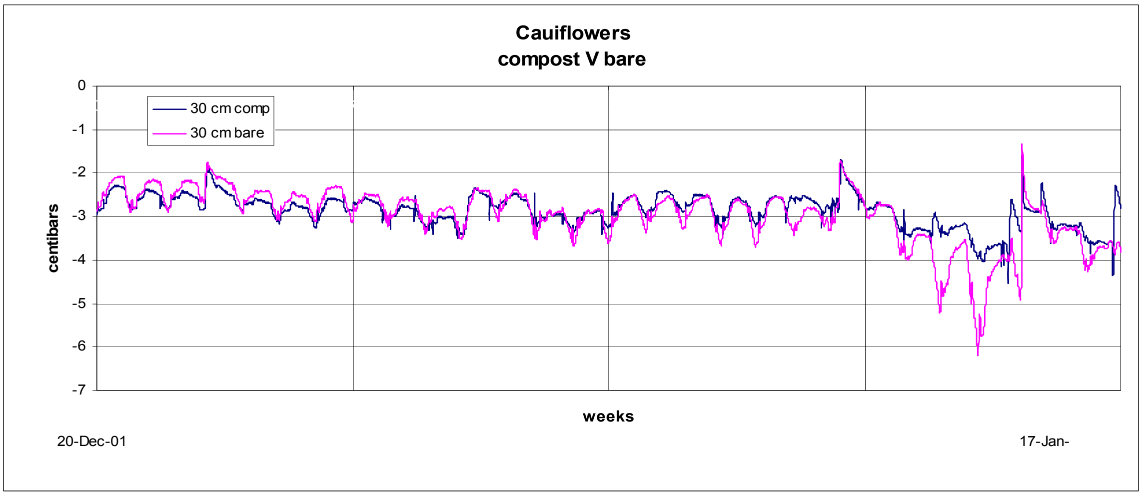
Table 5.4. Analysis of compost used at commercial demonstration Site 1

Analyte	Critical value	unit	Average value		Range	
			Compost-U	Compost-R	Compost-U	Compost-R
Carbon:Nitrogen ratio	<20	none	23.8	21.8	18 - 33	20 - 24
Nitrogen Drawdown Index	>0.5	none	0.5	0.3	0.2 - 0.8	<0.1 - 0.4
Organic matter		% DM	58.4	73.0	46 - 87	48 - 83
pH ($CaCl_2$)	5 - 7.5	pH unit	7.0	6.8	6.2 - 7.4	6.4 - 7.5
Electrical conductivity	-	dS/m	3.8	5.4	1.6 - 5.7	3.9 - 7.2
Toxicity (potting mix test)	> 60	%	92.3	58.8	<5 - 120	20 - 98
Moisture content		n/a	41.5	48.8	36 - 46	42 - 55
Total Nitrogen	> 100	% DM	1.5	2.0	1.1 - 1.7	1.4 - 2.4
$NH_4 + NO_3$	> 100	mg/L	127.3	89.8	<1.0 - 220	55 - 160
NH_4 nitrogen		mg/L	27.2	60.8	<1.0 - 67	12 - 160
NO_3/NH_4 ratio	>0.14		140.7	2.0	<0.01 - 450	<0.01 - 3.6
Phosphorous - Total (P)		% DM	0.8	1.1	0.3 - 1.3	0.7 - 1.4
Potassium (K)		% DM	0.7	1.0	0.3 - 0.96	0.82 - 1.2
Calcium (Ca)		% DM	7.2	3.1	4.1 - 12.0	3.0 - 3.2
Magnesium (Mg)		% DM	0.4	0.4	0.3 - 0.4	0.4 - 0.42
Iron (Fe)		% DM	0.3	0.1	0.2 - 0.3	0.13 - 0.16
Sulphur (S)			0.4	0.6	0.32 - 0.4	0.58 - 0.65
Manganese (Mn)		mg/kg	154.5	240.0	69 - 240	190 - 290
Zinc (Zn)		mg/kg	100.0	460.0	80 - 120	450 - 470
Copper (Cu)		mg/kg	53.0	96.5	53.0	95 - 98

Table 5.5. Water applied, E-pan evaporation and resultant crop factor at the Commercial compost demonstration Site-1

Week ending	Rain gauge	E-pan evaporation	Crop factor
27 December 2001	72	56.4	1.28
3 January 2002	53	54	0.98
10 January 2002	63	52.2	1.21
17 January 2002	77	61.2	1.26
24 January 2002	65	56.8	1.14
31 January 2002	87	58.5	1.49
6 February 2002	126	65.6	1.92
13 February 2002	113	64.2	1.76
20 February 2002	90	50.2	1.79
Totals	746	519.1	1.44





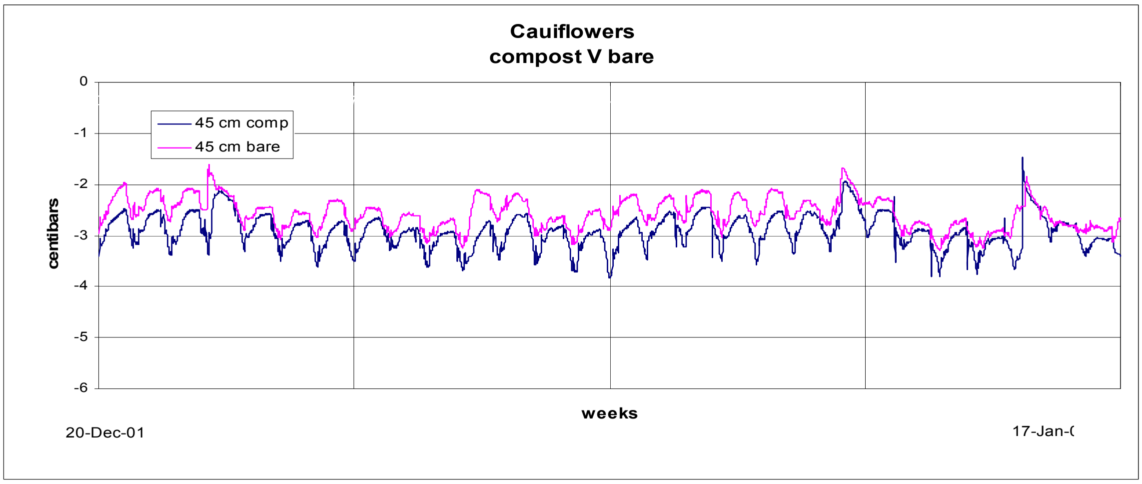
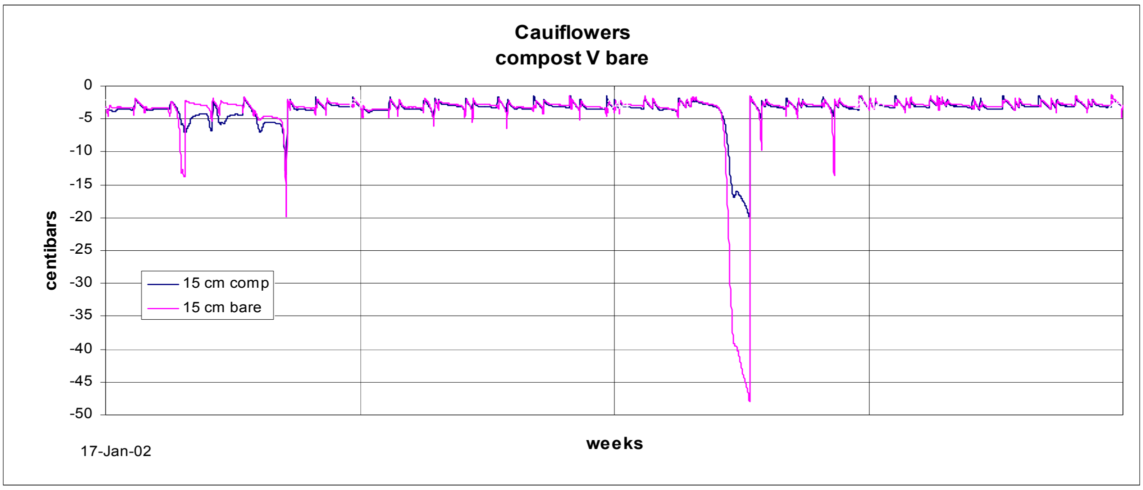
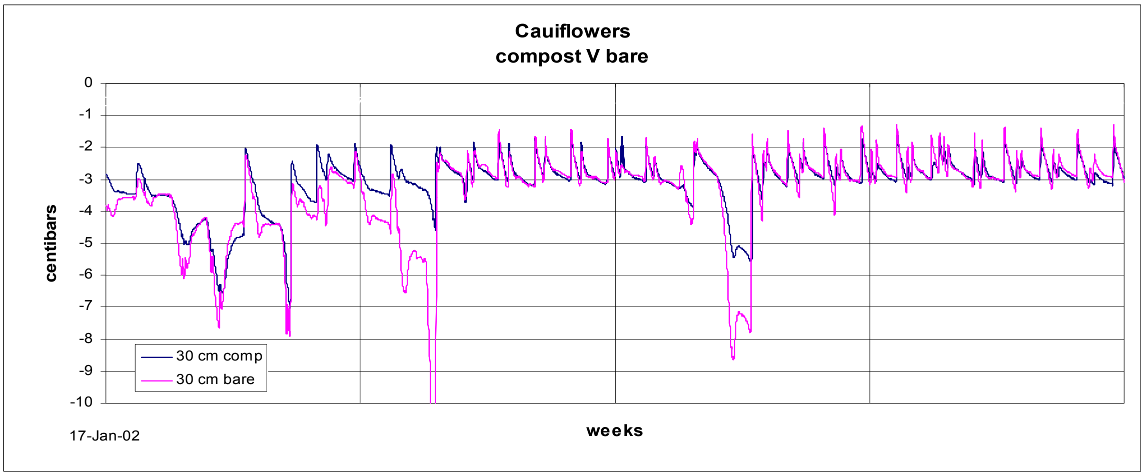


Figure 5.3. Graphs for the tensiometers at 15, 30 and 45 cm depth for period 20 December 2001 (planting), to 17 January 2002.





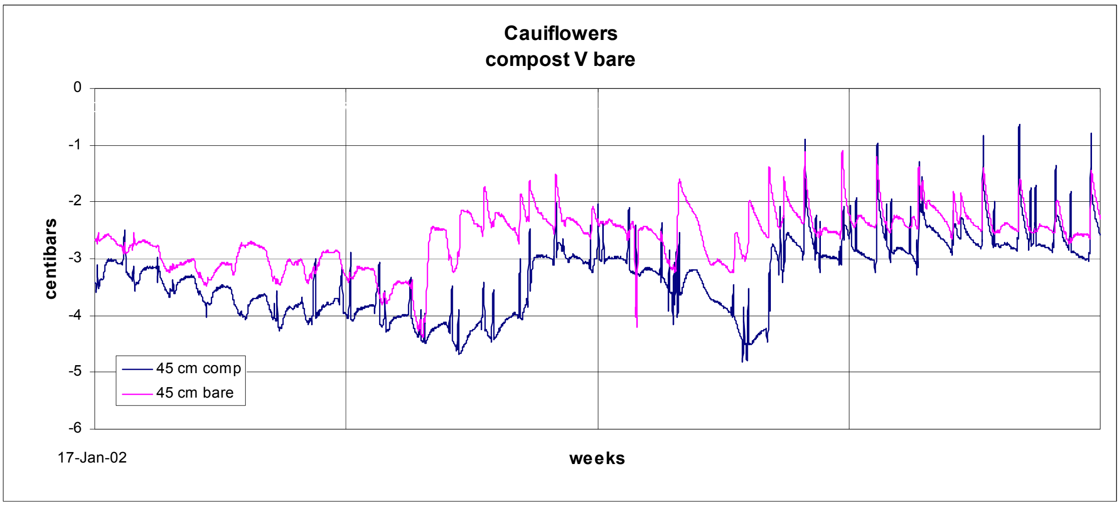


Figure 5.4. Graphs for the tensiometers at 15, 30 and 45 cm depth for the period 17 January 2002 to 14 February 2002.

Crop results

Statistical analysis is not valid within these demonstration sites, however sub plot data indicates that when there are reasonable differences between treatments, it is likely that a trend is being demonstrated.

It was not possible to sample harvest all of the carrot trials, however we were able to collect the growers harvest details. With the potato crop, we relied on the commercial harvest and the pack house was able to provide full information on the pack out and quality assessment for each treatment.

Crop 1 - Carrots

Yields, expressed as t/ha, from 10 hand harvested sub plots per treatment are provided in Table 5.6 and are graphed in Figure 5.5.

The results indicate that both composts improved yield and marketable yield was greatest with Compost-U. This compost also produced a larger percentage of large carrots, fewest rejects and least weight of carrot tops.

Table 5.6. Carrot yields (t/ha) from first crop at Compost demonstration Site 1

Treatment	Total	Marketable	Large marketable	Reject	Forked	Total tops	N°. of carrots
Compost-R	60.41	44.27	25.05	16.14	5.28	15.42	557
Compost-U	58.36	51.44	36.64	6.92	0.23	12.26	552
Control	56.22	43.56	24.10	12.66	3.88	13.91	547

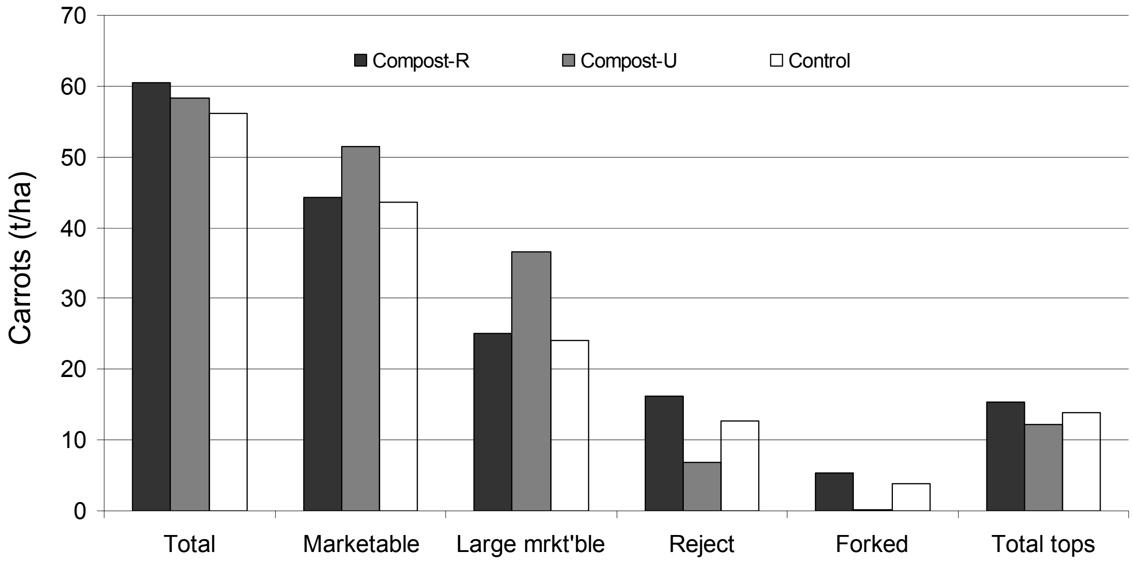


Figure 5.5. Yields of carrots from first crop at Site 1.

Crop 2 - Cauliflower

Cauliflower was the second crop at Site 1 and the treatr harvests in late November. There was no detectable in the yields in t/ha (Table 5.7) are based on average heac

Prior to commencement of Site 1, the grower had report uniformity in a Freemont cauliflower crop that was plant illustrated in the photograph (Figure 5.6) taken during th cauliflower laid out along the row.

The grower considered that part of this effect may have *(Plasmodophora brassicae),* a disease that was becomi property.

Club root damage was assessed following harvest by sc selected cauliflower plants in each treatment. The resul damage was visually assessed on a scale of 0 to 5 whe were severe club root symptoms. The results were incc

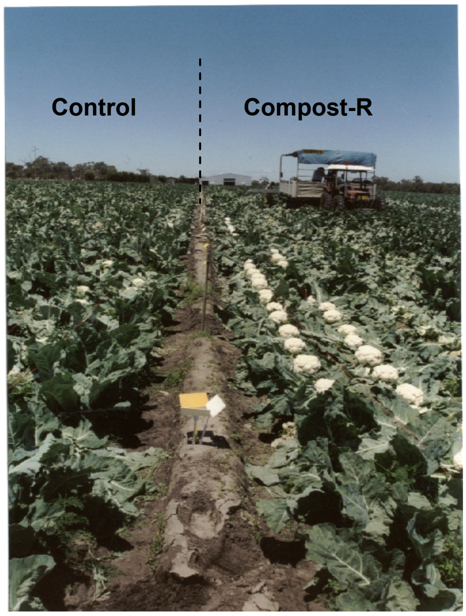


Figure 5.6. Harvested cauliflower in area treated with Compost-R compared to adjacent

Table 5.6. Cauliflower yield (t/ha) from the second crop at site 1

Treatment	Yield
Compost-R	26.1
Compost-U	30.7
Control	26.9

Table 5.8. Cauliflower club root (Plasmodophora brassicae) assessment using a 0 to 5 rating where 0 is no damage and 5 is severe damage, 2nd crop at Site 1

Treatment	Club root score						Overall rating
	Rating/score						
	0	1	2	3	4	5	
Compost-R	10	11	10	4	3	1	1.58
Compost-U	18	8	8	4	3	1	1.26
Control	16	4	9	9	3	0	1.44

Crop 3 - Second carrot crop

With the second carrot crop, each compost treatment with its adjacent control was planted one week apart and each was harvested four days apart. Treatments were sample harvested around mid January 2003 and yields together with aspects of carrot quality are recorded in Table 5.9, and graphed in Figure 5.7.

Table 5.9. Carrot yields (t/ha) from second carrot crop at Site 1

Treatment	Total	Marketable	Rejects	Forked	Tops	% Marketable
Compost-R	58.01	35.43	22.57	1.98	14.52	61.09
Control-R	59.63	42.07	17.56	2.31	15.31	70.56
Compost-U	55.05	31.70	23.35	0.46	13.32	57.59
Control-U	53.20	36.07	17.13	1.26	12.81	67.80

Note that Compost-U and its control were harvested 5 days later than Compost-R and its control.

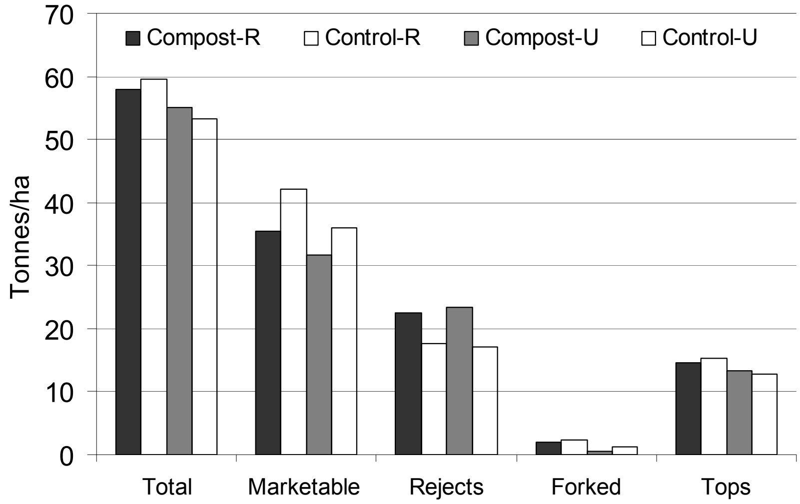


Figure 5.7. Carrot yields from second carrot crop at Site 1.

Crop 4 - Potato

The fourth crop at Site 1 involved two planting dates one week apart and two different potato varieties. Compost-R and its adjacent control were planted to the variety Mondial and Compost-U and its control was planted to the variety, Royal Blue. The area was commercially harvested and the results including a breakdown of the grades are provided in Table 5.10.

Table 5.10. Commercial potato harvest (t/ha) from the fifth crop at Site 1

Treatment	Total	Marketable	Reject
Compost-R variety *Mondial*	40.81	38.08	2.73
Control-R	39.58	37.29	2.29
Compost U *variety Royal Blue*	46.02	44.85	1.17
Control-U	49.97	48.69	1.28

Crop 5 - Carrots

The fifth crop at Site 1 was again carrots and was harvested in Early April 2004. We were unable to sample harvest the crop, however the grower supplied commercial harvest information including levels of reject as provided in Table 5.11.

Table 5.11. Commercial carrot harvest (t/ha) from the fifth crop at Site 1

Treatment	Total	Marketable	Reject
Compost-R	84.82	53.57	31.25
Compost-U	85.04	57.57	27.46
Control	85.57	61.56	24.01

Results

SITE 2

Soil analysis

The six treatment blocks were soil sampled in early November 2002 at two depths, 0–30 cm and 30–45 cm and thirty sub samples were collected per plot from 0 to 10 cm and 30 to 45 cm soil depth. The results are presented in Table 5.12, however due to analysis cost overruns associated with the Medina research program, soil samples collected following the final crop were archived without analysis.

Compost analysis

Table 5.12. Analysis* of compost used at the Commercial compost demonstration Site 2

Analyte	Critical/ ideal value	Unit	Compost					
			U 6 Caulifl. Nov. '02	R 6 Caulifl. Nov. '02	U 7 Carrot Mar. '03	R 7 Carrots Mar. '03	U 8 Caulifl. Oct. '03	R 8 Caulifl. Oct. '03
Carbon Nitrogen Ration	< 20/< 17	none	20	27	43	42	19	18
Nitrogen Drawdown Index	> 0.5	none	0.31	0.47	0.51	0.59	1.00	0.95
Organic matter		% DM	54	86	61	76	56	82
pH ($CaCl_2$)	5 - 7.5	pH units	6.8	6.3	8.5	6.4	6.8	5.8
Electrical conductivity	-	dS/m	5.80	2.95	9.15	8.00	7.00	6.15
Toxicity	> 60	mature %	6	91	< 6	70	89	66
Moisture content		n/a	27	58	39	37	46	58
Total Nitrogen	> 1.0/1.4	% DM	1.6	1.9	0.83	1.1	1.7	2.6
NH_4 + NO_3	> 100	mg/L	48	35	370	59	270	190
NH_4 nitrogen		mg/L	36.0	< 0.1	370.0	13.0	7.7	6.1
NO_3/NH_4 ratio	> 0.14	(m/l)	0.25	-	< 0.02	3.50	34.00	31.00
Phosphorous - Total (P)		% DM	1.0	0.8	1.3	0.8	1.2	1.0
Potassium (K)		% DM	0.58	0.56	0.88	0.9	0.88	1
Calcium (Ca)		% DM			5.3	2.5	5.2	3.6
Magnesium (Mg)		% DM			0.4	0.44	0.36	0.39
Iron (Fe)		% DM			0.48	0.23	0.25	0.14
Sulphur (S)		% DM					0.85	0.82
Manganese (Mn)		mg/kg			280	920	330	310
Zinc (Zn)		mg/kg			330	620	250	630
Copper (Cu)		mg/kg			200	200	71	120

* All analysis conducted in accordance with AS 4454, Australian standards for compost, soil conditioners and mulches, by Collex laboratories, Adelaide, SA.

Crop performance

Crop 1 - Cauliflower

Freemont Cauliflower was planted in Late November 2002 to early December with the two replicates being planted a week apart. Each planting was harvested over a 2 week period in a total of five harvests and individual head weights were recorded.

There were no identifiable impacts of treatment on the quality of the cauliflower heads and the yields reported in Table 5.13 are in t/ha based on average head weights. The numbers of heads cut in each of the five harvests is averaged over the two replicates and is graphed in Figure 5.8.

No club root *(P. brassicae)* was detected in the demonstration area.

Table 5.13. Cauliflower yield (t/ha) from first crop at the Commercial compost demonstration Site 2

Treatment	Replicate		Total
	1	2	
Compost-R	36.63	38.13	37.38
Compost-U	39.05	38.97	39.01
Control	36.45	38.06	37.25

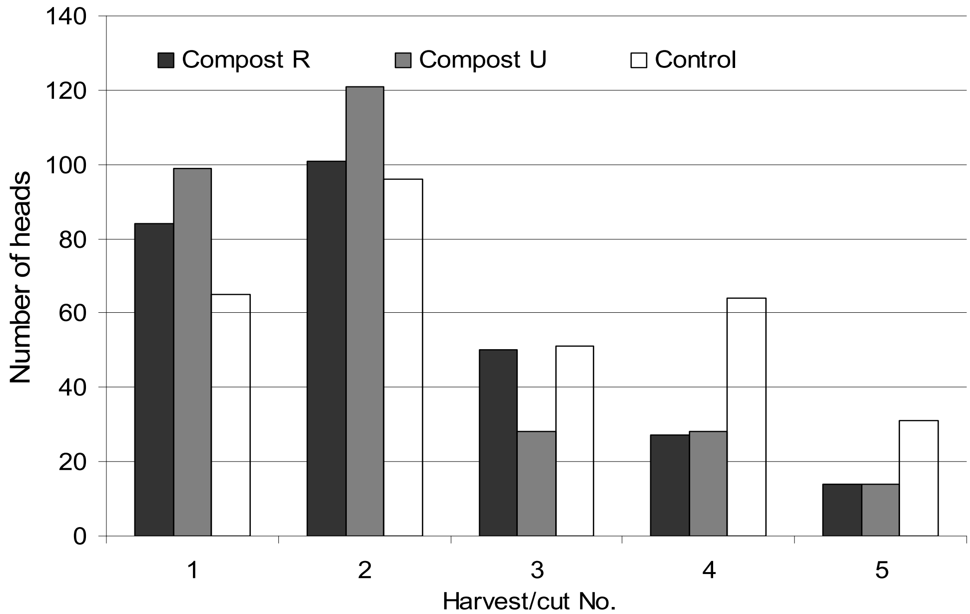


Figure 5.8. Analysis of heads cut over five harvests of the second cauliflower crop at the Commercial compost demonstration Site 2.

Crop 2 - Carrots

Carrot yields averaged over the two replicates are graphed in Figure 5.9 and more detailed data is provided in Table 5.14, including number of carrots harvested from the 10, 2 m by one double row of carrots harvested from each treatment.

Table 5.14. Yields (t/ha) and numbers of carrots harvested from second crop at the Compost demonstration Site 2

Treatment		Tonnes/ha					Total N°. carrots harvested
		Total	Marketable	Total rejects	Forked	Tops	
Compost-R	Rep. 1	58.7	38.2	20.5	4.75	8.7	246
Compost-U		61.7	46.3	15.4	1.17	9.1	212
Control		56.8	43.9	18.9	4.99	8.7	230
Compost-R	Rep. 2	57.5	42.6	14.8	0.97	8.6	263
Compost-U		64.1	51.1	13.0	1.88	11.3	214
Control		63.1	43.6	19.5	6.95	10.0	237
Compost-R	Average	58.1	40.4	17.7	2.86	8.7	255
Compost-U		62.9	48.7	14.2	1.52	10.2	213
Control		59.9	43.8	19.2	5.97	9.3	234

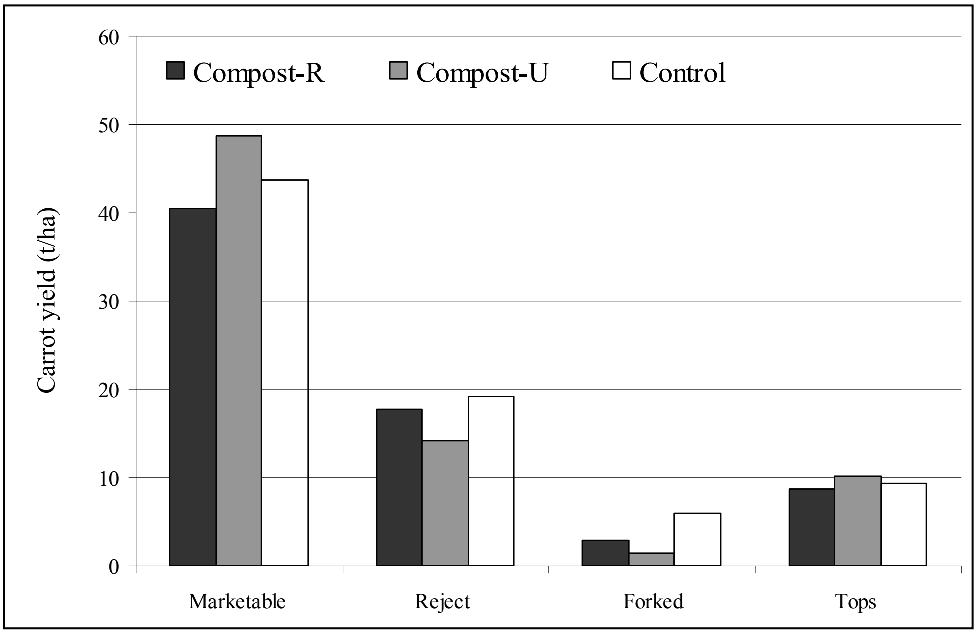


Figure 5.9. Carrot yields (t/ha) from second crop at the Compost demonstration Site 2.

Leaf samples were also collected from the second carrot crop on and are summarised in Table 5.15.

Table 5.15. Leaf analysis results from youngest fully expanded carrot leaf collected on 06/06/03 from the second crop at the Compost demonstration Site 2

Nutrient	Unit	Compost-R	Compost-U	Control	Recommended range	Critical value
Nitrogen	%	4.07	4.09	4.07	2.00-3.50	1.80
Phosphorus	%	0.45	0.47	0.45	0.20-0.35	0.18
Potassium	%	5.38	5.35	5.15	2.5-4.5	2.00
Calcium	%	1.44	1.32	1.38	1.4-3.0	
Magnesium	%	0.41	0.37	0.37	0.30-0.55	0.15
Sulphur	%	0.35	0.33	0.33	0.32-0.63	
Iron	mg/kg	121.0	114.0	139.0	120-300	
Copper	mg/kg	7.67	7.75	7.65	10-25	4.0
Manganese	mg/kg	52.8	47.0	49.2	130-350	< 50 (?)
Zinc	mg/kg	29.7	27.8	25.8	20-50	18.0
Boron	mg/kg	29.5	29.8	28.7	30-80	20.0
Sodium	%	0.45	0.44	0.46	0.46-4.5	
chloride	%	2.52	2.31	2.40	3.0-3.6	

Crop 3 - Cauliflower

The third and final crop at Site 2 was planted in Early September. Diamond Back moth was not adequately controlled and the harvest results, Table 5.16 were further compromised because only a single harvest was possible from the second replicate. Plant weights were also measured and are presented as averages per treatment.

Table 5.16. Cauliflower yield (t/ha) and average plant weight (kg) from the third crop at the Compost demonstration Site 2

Treatment	Marketable heads	Average plant wt
Compost-R	13.06	2.01
Compost-U	15.75	2.19
Control	10.53	2.16

Discussions – Sites 1 and 2

Soil analysis

Soil analysis was only completed for Site 1 and full details are provided in Appendix 5.1A for the top 15 cm of soil and in Appendix 5.1B for the 30 to 45 cm soil depth.

Changes and overall levels are similar to those measured at the nearby Medina research site and indicate increasing levels of soil carbon and general soil fertility. Some of the key values are depicted graphically in Figure 5.10 and 5.11.

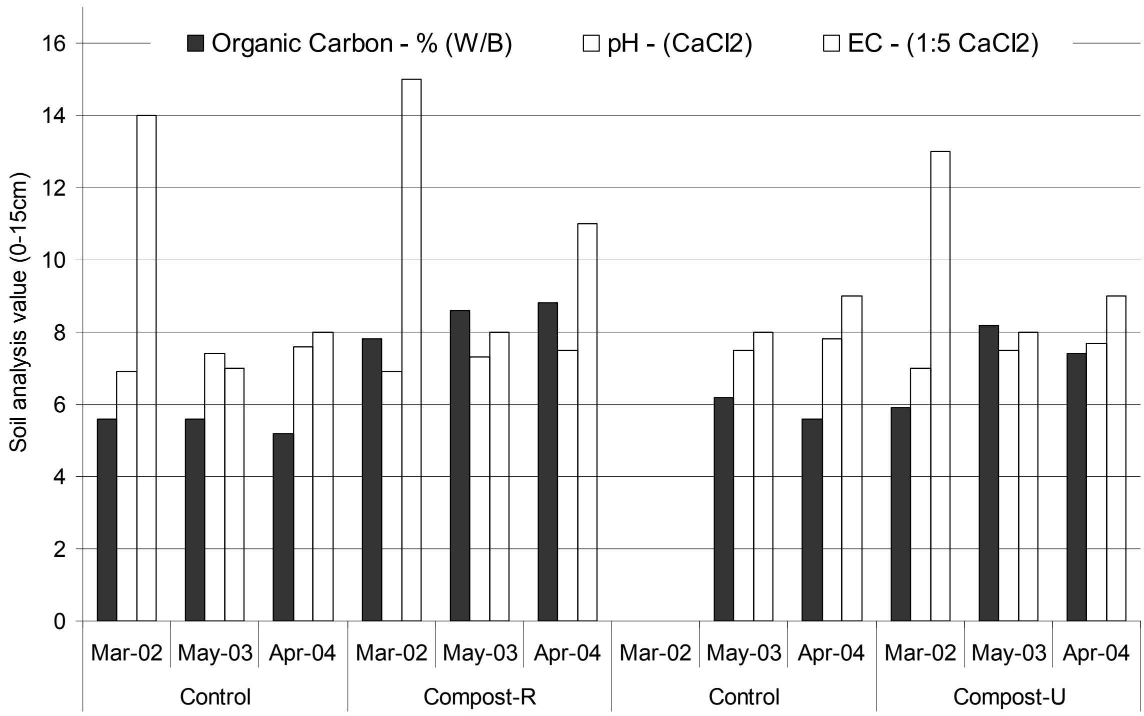


Figure 5.10. Changes in selected soil attributes over the period of five crops at the Commercial compost Site 1 in the top 15 cm of soil.

It is noteworthy that with soil phosphorus levels, total levels have increased dramatically while the levels of bicarbonate extracted (by the Olsen method) or available phosphorus have remained relatively constant. It is worth noting that work at the Medina Vegetable research site has indicated that the Olsen test will validly measure plant available phosphorus in compost amended soils and therefore provides a reliable method for adjusting fertiliser/inorganic phosphorus applications.

Compost quality

Composts analysis values for Site 1 are provided in Appendix 5.1 and these are summarised in Tables 5.4. Analysis for compost used at Site 2 is provided in Table 5.12. All analysis are in accordance with the Australian Standards for Compost, Soil Conditioners and Mulches, AS 4454-2003. Most compost's achieve close to the critical values considered to be of direct influence on compost performance, including Carbon Nitrogen ratio, Nitrogen Drawdown Index, Toxicity and various nitrogen values are met, although levels of available inorganic and hence soluble nitrogen are low.

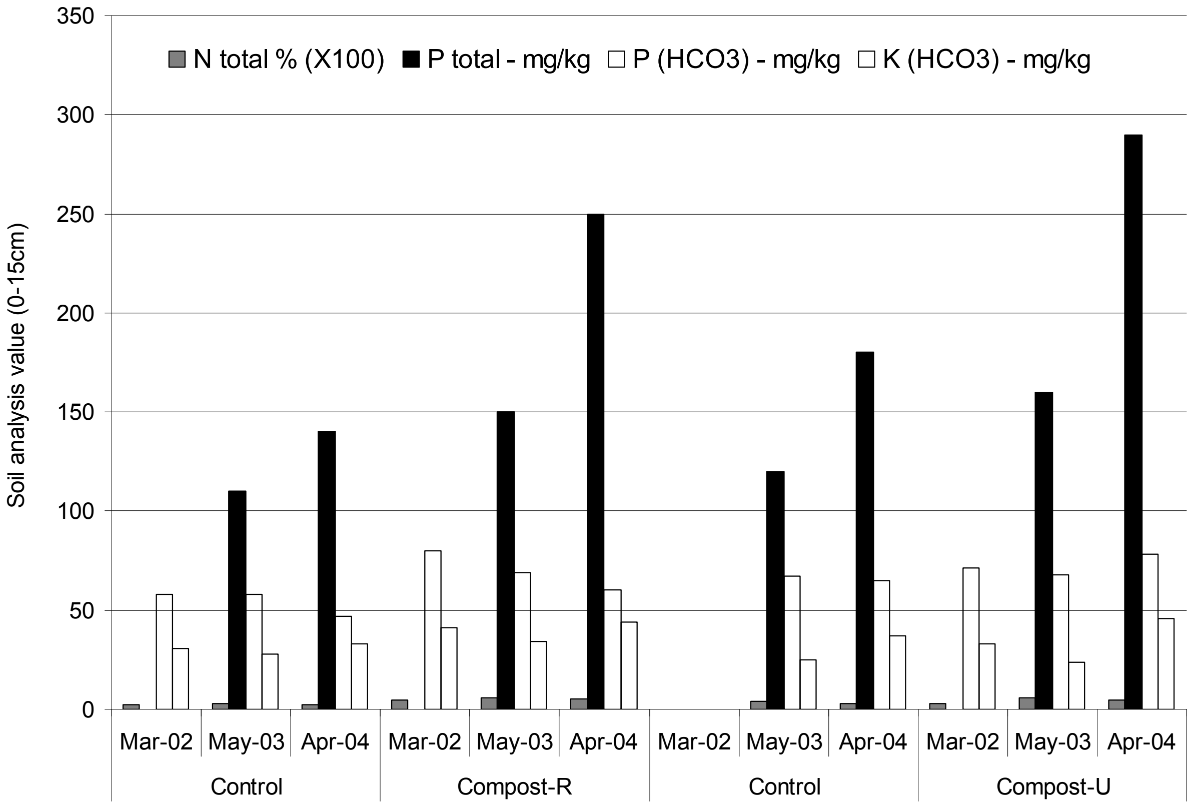


Figure 5.11. **Changes in selected soil fertility attributes over the period of five crops at the Commercial compost Site 1 in the top 15 cm of soil.**

Irrigation

The soil moisture graphs (Figure 5.3 and 5.4) indicate that the grower was managing soil moisture levels considerably above the generally accepted field capacity of 10 centibars. They also support findings at the Medina Research site that the regular use of compost increases soil volumetric water holding because when the soil is periodically allowed to dry down towards field capacity within the 15 to 30 cm active root zone, the compost treated areas consistently maintain higher moisture levels.

Crops

With the obvious similarities between the two sites, the results will be discussed in relation to crop type rather than individual plantings.

Carrot

Marketable yields from the four carrot trials suggest that Compost may be improving marketable yields with initial application, although there is an apparent discrepancy between the performances on the two types (Table 5.17).

Table 5.17. Summary of marketable carrot yields in the four carrot plantings at Sites 1 and 2

Treatment	Site 1			Site 2	Average
	Crop 1	Crop 3	Crop 5	Crop 2	
Compost-R	44.27	35.43	53.57	48.71	43.42
Compost-U	51.44	31.70	57.57	40.41	47.36
Control	43.56	39.07	61.56	43.75	47.00

Numbers of carrots harvested from the three trials that we sample harvested are provided in Table 5.18. With the exception of the final crop at Site 2, numbers of carrots were not influenced by treatment.

Table 5.18. Numbers of carrots harvested at three carrot trials

Treatment no.	Site 1		Site 2
	Crop 1	Crop 3	Crop 2
Compost R	557	271	509
Compost U	552	270	426
Control	547	267	448

With the possible exception of the carrot crop at Site 2, differences in compost analysis do not provide an explanation of differences in yields. At site 2, the toxicity and the associated low Nitrate/Ammonium nitrogen ration for Compost-U provide a possible explanation for the reduced carrot numbers and yields compared to Compost-R. The toxicity and the associated low Nitrate/Ammonium nitrogen ration for Compost-U at Site 2 may explain the apparent reversal in its performance compared to the first carrot crop at Site 1 are likely to explain the reduced number of carrots harvested for Compost-U.

The results indicate that initial compost applications can improve marketable and total (data not provided) carrot yields. The indicated decline in compost performance with successive compost applications at Site 1 is most notable with Compost-U, however it needs to be acknowledged that while this was only the second application of this compost, it was the ninth application of Compost-R.

Increasing but not necessarily appropriately balanced soil fertility with consecutive compost applications provides a possible explanation for this trend and provides added reason for a need to manage fertiliser use in order to accommodate contributions from compost. The soil analysis data (Table 5.3 and Figure 5.11) show increases in potassium and phosphorus levels in particular.

The relatively small change in available (Bicarbonate extracted) phosphorus relative to the total phosphorus value within the compost treated areas perhaps indicates that more of the phosphorus is being held in an organic form.

Cauliflower

Recorded increases in marketable cauliflower yields (Table 5.18) indicate that Compost-U was more consistent in its benefits.

The growers observations that compost resulted in more uniform and earlier maturity, were confirmed by the indicated distribution of cut heads over the five harvests in the first cauliflower crop at Site 2 (Figure 5.8). This improvement resulted in the grower needing one less harvest.

We were not able to confirm that compost had any effect on Club root disease (*P. brassicae*), Table 5.7. It may be possible that this observation reported by the grower over several crops may have resulted from compost treated soils retaining the standard fungicide treatment, Shirlan® longer and allowing its proven effectiveness to reduce or at least delay the impact of Club root. There have been suggestions that Shirlan® is not as effective against this disease on coarse sandy soils.

Table 5.18. Marketable cauliflower yields (t/ha) from three cauliflower crops at Compost demonstration sites 1 and 2

Treatment	Site 1	Site 2	
	Crop 2	Crop 1	Crop 2
Compost-R	26.1	39.01	13.06
Compost-U	30.7	37.38	15.75
Control	26.9	37.25	10.53

Potato

The single potato crop at Site 1 provided inconclusive results (Table 5.9) and did little to clarify earlier work (Paulin *et al*. 1999 and 2002). These earlier results indicated that the use of compost can reduce emergence, but that yield was largely unchanged because individual potato tubers were larger.

It is possible that previously recorded reduction in stem emergence may have been the result of increased soil moisture around the potato seed resulting during seed germination. This consideration had resulted in the grower changing the method of compost application and banding it on the surface, at or just prior to stems emergence.

Previous results (Paulin *et al.* 2002) using compost applied prior to planting potatoes on light loam soils at Manjimup, to the South-South East of Perth have indicated improved yields and quality.

Progress with applying compost to vegetables

A significant barrier to compost use has been the availability of suitable application equipment. The grower involved with this project together with the producer of Compost-R and NuFarm equipment suppliers have progressively developed a machine that is capable of applying compost as a surface application or in a narrow band, either on the surface or into a furrow.

Application equipment capable of varying application method.

Furrow application of compost.

With seeded crops like carrots they can now restrict compost application to the surface of the bed. By not applying compost into the wheel tracks, this has effectively reduced a 25 t/ha application down to 20 t/ha. A bed rotary cultivator is then used to lightly incorporate it into the top 1-2 cm of the bed. This maximises the potential for the compost application to reduce wind erosion and therefore minimises consequent loss of seedlings at emergence.

Banding compost is used when planting crops such as cauliflowers and allows the compost to be concentrated into a narrow furrow. Planting then occurs directly into this area either immediately after compost application or within a couple of days.

A bed rotary cultivator being used to lightly incorporate compost.

Truck capable of accurately applying larger quantities of compost.

Another method of broadcasting compost is provided by specially fitted trucks that feature wide tires to minimise compaction and a walking floor to deliver compost to dual spinners at the rear. They are fitted with load cells so that the application rate can be monitored and adjusted from the driving position.

Appendix 5.1. Analysis* of compost used at commercial demonstration site, Site 1.

Analyte	Critical/ ideal value	Unit	Compost									
			U1 Carrots E. Mar. '02	R 1 Carrots E. Mar. '02	U 2 Cauliflower L. Aug. '02	R 2 Cauliflower L. Aug. '02	U 3 Carrots E. Jan. '03	R 3 Carrots E. Jan. '03	U 4 Potato L. May '03	R 4 Potato L. May '03	U 5 Carrot M. Dec. '03	R 5 Carrot M. Dec. '03
Carbon Nitrogen Ration	< 20/17	none	33	23	24		26	20	20	24	16	20
Nitrogen Drawd'n Index	> 0.5	none	0.41	0.20	0.63		0.81	< 0.1	0.20	0.40	0.27	0.26
Organic matter		% DM	62	78	50		87	48	47	83	46	83
pH ($CaCl_2$)	5 - 7.5	pH units	7.4	6.7	7.4		6.2	7.5	6.7	6.7	7.2	6.4
Electrical conductivity	-	dS/m	1.60	3.85	3.10		3.75	7.20	5.00	3.60	5.65	6.90
Toxicity	> 60	mature %	120	67	93		86	20	<5.0	50	70	98
Moisture content		n/a	46	43	45			42	39	55	36	55
Total Nitrogen	> 1.0/1.4	% DM	1.1	2	1.2		2	1.4	1.4	2	1.7	2.4
NH_4 + NO_3	> 100	mg/L	< 1.0	55	59	Not sampled	110	160	120	88	220	56
NH_4 nitrogen		mg/L	< 1.0	12.0	20.0		5.9	160.0	67.0	51.0	16.0	20.0
NO_3/NH_4 ratio	> 0.14	(m/l)	-	3.60	2.00		110.0	< 0.01	0.75	0.73	450.0	1.80
Phosphorous - Total (P)		% DM	0.3	0.9	0.7		0.8	0.7	1.0	1.2	1.3	1.4
Potassium (K)		% DM			0.3		0.8	0.82	0.59	0.91	0.96	1.2
Calcium (Ca)		% DM			12.0				4.1	3.0	5.4	3.2
Magnesium (Mg)		% DM			0.39				0.29	0.41	0.39	0.42
Iron (Fe)		% DM			0.49					0.16	0.2	0.13
Sulphur (S)		% DM							0.32	0.58	0.39	0.65
Manganese (Mn)		mg/kg	69	190					240	290		
Zinc (Zn)		mg/kg	80	450					120	470		
Copper (Cu)		mg/kg	53	95					53	98		

* All analysis conducted in accordance with AS 4454, Australian standards for compost, soil conditioners and mulches, by Collex laboratories, Adelaide, SA.

SECTION 6 PhD PROGRAM AT THE UNIVERSITY OF WESTERN AUSTRALIA

Introduction

Conventional vegetable cropping involves repeated tillage, application of fumigants, such as Metham Sodium, fertilisers, pesticides and herbicides. The combination of such intense practices has detrimental impacts on soil biological populations and can result in severe damage to soil structure, to soil health and to the long term productivity of the soil (Bending *et al*. 2004; Kandeler *et al*. 1999; Wells *et al*. 2000). Practices that are able to increase the ability of the microbial population to recover from these disturbances and perform vital functions, such as nutrient cycling, are highly beneficial (Brussaard *et al*. 2004).

The importance of soil carbon or soil organic matter (SOM) to the healthy functioning of a soil ecosystem is widely recognised. Amending sandy soils with compost, can help increase SOM levels to support soil microbial populations (Albiach *et al*. 2000), suppress plant disease (Rotenberg *et al*. 2005), supply nutrients (Stoffella and Kahn 2001), improve soil physical properties such as structure (McGiffen *et al*. 2004) water holding capacity (Barzegar *et al*. 2002; Celik *et al*. 2004; Tester 1990) and help buffer chemical properties such pH and EC (He *et al*. 1992). A combination of these factors can result in compost amended soils producing higher plant yields providing system is managed correctly (Lalande *et al*. 2003; O'Malley *et al*. 2003; Paulin *et al*. 2004; Sikora and Szmidt 2002).

Soils with a higher proportion of silt and clay are better able to hold water, protect SOM from microbial degradation (McGiffen *et al*. 2004; McLaren and Cameron 1996) and potentially enhance some of the benefits of compost addition to sandy soil. The length of time added carbon will stay in the soil and the amount it will contribute to processes, such as nitrogen cycling, will depend upon factors such as soil type and environmental conditions but also on the quality of the amendment added (Bernal *et al.* 1998).

Nitrogen is a key nutrient for plant growth. Net N mineralisation rates provide a value of the plant available N released from the opposing processes of gross mineralisation (ammonification) and immobilisation. However, this gives no indication of the actual magnitude of N cycling within the system. Gross N flux's as determined by ^{15}N isotopic pool dilution are able to distinguish between the main productive (mineralisation) and consumptive (immobilisation) N processes and hence give information on the internal N cycling within the soil (Murphy *et al*. 2003). The magnitude of gross N flux's from soil organic matter and crop residues is highly dependant on biological activity (Bengtsson *et al*. 2003; Mishra *et al*. 2005: Murphy *et al*. 2003) and hence on the availability of carbon energy sources for the microorganisms involved (Bernal *et al*. 1998). For example, products that are high in microbially available carbon (such as plant residues and unprocessed manures), will stimulate an increase in microbial activity and possibly biomass as the product is decomposed. In doing so the nutrients held in that product will be released. These products are often high in nitrogen. The C:N ration of a product is commonly used as an indication of the amount of N likely to be released over a period of time (Hadas *et al*. 2004). However as much of the C in this measure may be microbially stable or unavailable it can not give a true indication of the impact in the short term (e.g. 10 week or less) decomposition and subsequent impact on crop performance (Gilmour 1998). Given vegetable crops have relatively short growing time it is the microbially available components of a product that will have greatest immediate effect on nutrient cycles. The stable or non–microbially available C will have benefits for the long term such as water holding capacity as mentioned earlier.

For horticultural systems management, it is the functional roles of the soil microbial population, particularly in terms of SOM decomposition and associated nutrient release that is of greater importance than the overall size or diversity of the population. Community response profiles (CRP's) indicate the functional diversity of the soil microbial community (Degens, 1999). Lower CRP values do not necessarily correspond to slower rates of a given microbial function such as SOM decomposition (Degens, 1998). However, soils with lower CRP's are considered to be more susceptible to stress and disturbance (Degens *et al*. 2001).

Objectives

The objectives of this PhD research are to investigate the impact of soil amendments, particularly greenwaste-based composts and clay on soil microbial populations. This has been in conjunction with this project and components of the trial programs at the Medina Vegetable Research Station. This program aims to develop our understanding of the biological component of soils combined with soil physical parameters, soil nutrient cycling to assist the development of sustainable management practices for vegetable production.

A summary of the main findings to date are presented. Additional analysis and interpretations of the results of these trials are currently being carried out, particularly from the Victorian trial hence are not included. For further and more detailed information please refer to publications resulting from the work as listed in Appendix 6.1 PhD Progress summary.

The thesis is due for completion in August 2005 and will be held by the University of Western Australia.

Methodologies

Laboratory incubation

Samples of 6 commercially available organic amendments were chosen. These were added at a rate equivalent to 30 m^3 ha^{-1} to soil collected from the Systems trial site at the Medina research station. Products included a pelleted poultry manure, the two green-waste based composts used in the Medina N fertiliser replacement trial, a vermi-compost, a straw based compost and a semi-composted grape marc. They were then incubated at 15°C and approx 75 per cent water holding capacity for up to 142 days. Moisture was adjusted weekly. On days 3, 9, 16, 23, 37, 51, 82, 107 and 142 samples were removed and analysed for microbial biomass carbon (MB-C), microbial activity and gross N mineralisation rates using the methods described below. The cumulative amounts of C mineralised (i.e. lost to the atmosphere) was calculated based upon the daily rates of CO_2-C production.

Field site description

Field samples were collected from the Nitrogen fertiliser replacement trial (Section 1) and Systems trial (Section 3) sites at the Medina Research Station, Western Australia.

At the WA fertiliser replacement trial, surface soil samples (0-15 cm) were collected at planting and at harvest for each of the lettuce crops from a selection of plots. It was only possible to analyse selected treatments, they included 4 replicates of the non-amended soils, and high and low rates of both Compost A and Compost B that were receiving the mid rate of 300 kg of N per crop. The control and high rate of compost A and B which received no inorganic N fertiliser were also selected.

At the Systems trial site samples were collected on 20.6.02, after Metham Sodium fumigation and prior to application of amendments, at harvest time for both the carrot crop, 20 February 2003 (149 days after amendment incorporation) and lettuce crop, 3 June 2003 (303 days after amendment incorporation.

At the Victorian fertiliser N replacement trial (Section 2), surface (0-15 cm) soil samples were collected on 22 April 2003 at harvest of lettuce crop, complete analysis of the isotopic pool studies on the Victorian data have not been finalised and are not included in this report.

N mineralisation rates

Gross N mineralisation rates were determined on soils collected at the time of lettuce harvest using ^{15}N isotopic pool dilution techniques. The principle and assumptions of ^{15}N isotopic pool dilution has been reviewed elsewhere (Murphy *et al*. 2003). Soil (200 g) from each container was weighed into 250 mL cups and homogeneously labelled with $(^{15}NH_4)_2SO_4$ at 60 atom per cent ^{15}N. The ^{15}N solution was applied at a rate of 3 mg NH_4^+-N g^{-1} soil delivered in 3 mL. Containers were covered to minimise water loss and incubated at 15°C. At three time intervals after ^{15}N-labelling (2, 24 and 48 h), 50 g of ^{15}N-labelled soil (dry wt. equivalent) was removed and the NH_4^+-N and NO_3^--N extracted using 200 mL 0.5 M K_2SO_4. Soil plus solution was shaken for 1 h, centrifuged at 2000 rpm for 5 min. and then filtered through Whatman number 41 filter papers using Buchner funnels under vacuum. Filtrate was collected and stored at -18°C until subsequent analysis. All filtrates were analysed for NH_4^+-N and NO_2^--N + NO_3^--N on a Skalar San plus system™ continuous flow colourmetric analyser (Skalar, Breda, Netherlands).

The diffusion method of Brooks *et al*. (1989) with slight modifications was used to obtain separate ^{15}N enrichments for both the NH_4^+-N and NO_3^--N pools. A continuous flow system using a Tracermass Ion Ratio Mass Spectrometer and Roboprep preparation system, (Europa PDZ, UK) was used to determine ^{15}N enrichments of the acidified diffusion discs. Gross N mineralisation rates where determined analytically as described by Kirkham and Bartholomew (1954).

Re-mineralisation of ^{15}N was apparent in the compost and clay treated soils as indicated by an increase in the ^{15}N enrichment of the NH_4^+ pool (data not shown), hence, all gross N mineralisation rates were determined over the 2 to 24 hour time period. Net N mineralisation rates were calculated as the difference between total inorganic ^{14}N pools in the extracts on subsequent sampling times divided by the time between the sampling periods.

Microbial biomass

The fumigation-extraction method (Vance *et al*. 1987) was used with a 7-day chloroform fumigation period as recommended by Sparling and Zhu (1993) for similar Western Australian soils. Briefly, 20 g (dry weight equivalent) of soil, either fumigated or not fumigated was mixed in a 1:4 ratio with 0.5 M K_2SO_4, shaken for 1 h and filtered through Whatman number 42 filter papers that had been pre-washed with de-ionised water. Extracts were then stored at -18°C until analysis.

Microbial biomass-C (MB-C) was determined using high temperature oxidation (TOC-5000A, Shimadzu, Kyoto, Japan) and calculated as the total oxidisable carbon flush multiplied by a k_{EC} of 2.64 (Vance *et al*. 1987).

Microbial biomass-N (MB-N) was analysed by ninhydrin-positive compounds (NPC; Brookes *et al*. 1985) and calculated as the NPC flush multiplied by a k_{EN} of 3.5 (Sparling *et al*. 1993). The microbial quotient was calculated as (MB-C/C org) and is used to normalise microbial biomass data from soils with different levels of C (Breland and Eltun 1999; Sparling, 1997).

Microbial activity (CO_2-C production)

Soil CO_2 production rates where determined using static incubation vessels (7 day, 15°C) containing the equivalent to 50 g dry soil and 10 mL of 0.5 M KOH. A sub-sample of KOH was mixed with BaCl and then titrated with 0.1 M HCl to an end point pH of 8.3 (Anderson, 1982). The metabolic quotient, qCO_2 was calculated as the CO_2 production rate divided by MB-C to give a relative measure of the activity of the microbial biomass.

Microbial diversity - Catabolic Response Profiles (CRP)

The microbial diversity was determined using substrate induced respiration on soils that had been pre-incubated for 1 week, 20°C at 70 per cent WHC. Twenty five substrates were used and all were pH adjusted to within range 5.5-6.0. A treatment of double de-ionised water was also included to obtain a base level reading and to remove the effect of moisture from the analysis (Degens, 1997: 1998). The CO_2 produced after a 4 hour incubation was then sampled from the head space and injected into an infa-red gas analyser. The CRP value was determined on a standardised CO_2 response (Degens 1998a, b).

Catabolic diversity was characterised by both catabolic richness, defined as the number of substrates utilised, and catabolic evenness, defined as the variation in amount of individual substrate utilisation. Catabolic evenness was calculated using the Simpson-Yule index is defined as $E = 1/\sum p_i^2$, where p_i = CO_2-C production from individual organic-substrates as a proportion of the total CO_2-C production from all organic-substrates. In this study the maximal values for this index is 25 if all organic-substrates are utilised equally. A higher index value is interpreted as greater catabolic diversity within the active microbial population.

Statistical analysis

One way ANOVA's were performed using SPSS version 10 (1999). Canonical analysis of principle coordinates was used to determine treatment differences over the range of substrates in catabolic diversity measures. The CAP program (Anderson 2004) was used. A ll statistical analysis were performed to $p < 0.05$ significance unless otherwise stated.

Results

Incubation experiment

The rate of CO_2-C production and the cumulative amount of C lost was low in the control soils (Figure 6.1). The pelleted poultry manure had a high initial rate of microbial activity however this was not able to be sustained and by the end of the incubation had fallen to similar levels as the control soil.

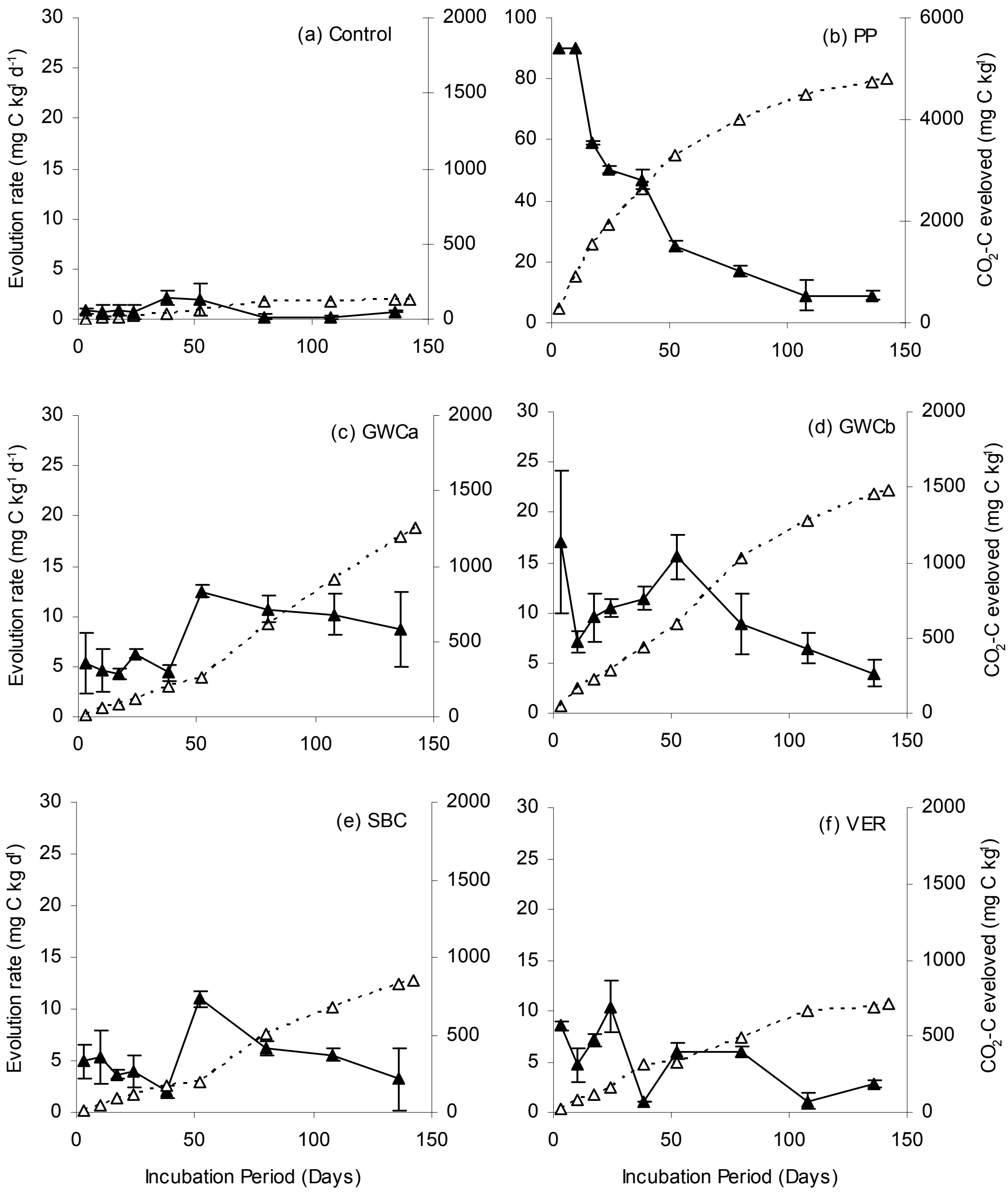


Figure 6.1. Carbon dioxide production rates (full lines, left axis) and cumulative CO2-C evolved (dashed lines, right axis) from soils. Bars indicate standard error of the mean. N = 4. PP = pelletised poultry manure; GWCa = green-waste based compost A; GWCb = green-waste based compost B; SBC= straw based compost; VER = vermicast, Note: Different scale on PP graph.

Rates of CO_2-C production in the composted products were higher than in the control soils. They were lower than the manure and more consistent over time indicating an ability to support microbial populations longer than the poultry manure.

While we are unable to exactly determine the amount of C lost from the PP due to it exceeding the capacity of our alkaline traps we know it was greater than 50 per cent of the C originally added. Ranking the products in the order of amount of added C lost indicates:

Poultry manure > grape marc > Green-waste compost B ≥ Green-waste compost A ≥ straw based compost > Vermi-compost.

Gross N mineralisation rates were higher in amended soils than in the control soils, so too were MB-C and MB-N levels (data not presented here).

Field results

Nitrogen (N) mineralisation rates

WA - N fertiliser replacement trial

Gross N mineralisation rates were higher in compost amended plots than in control plots however these differences were only significant for compost A, Table 6.1. Net N mineralisation rates were lowest in control plots receiving inorganic fertiliser and highest in compost B plots (Table 6.1). Overall, there was no significant effect of inorganic fertiliser application on either gross N mineralisation ($F = 0.006$, $p = 0.939$, $n = 22$) or net N mineralisation rates ($F = 0.25$, $p = 0.622$, $n = 22$).

Table 6.1. WA Fertiliser replacement trial: Data from harvest of the fourth lettuce crop. All compost results included in this table are from the high rate (60 m3) application of composts. Plots were receiving either no inorganic fertiliser or fertiliser at rate 3 (recommended commercial rate). Different letters denote significant differences between treatments ($p < 0.05$), numbers in brackets indicate standard error of the mean

WA Fert replacement trial	Microbial Biomass C	CO_2-C rate	Gross N min	Net N Min
	mg kg^{-1}	mg kg^{-1} d^{-1}	mg kg^{-1} d^{-1}	mg kg^{-1} d^{-1}
Control	40.51 (3.13)a	.711 (0.27)ab	0.75 (0.13)a	1.07 (0.21)a
Control + Fert	21.42 (4.81)a	0.76 (0.21)ab	0.49 (0.06)a	0.31 (0.42)ac
Compost A	328.09 (39.89)b	10.48 (0.77)c	2.02 (0.61)b	1.30 (0.57)ab
Compost A + Fert	433.29 (18.33)c	15.38 (1.55)d	2.64 (0.58)bc	1.17 (0.27)a
Compost B	278.51 (18.95)b	3.55 (0.59)be	1.34 (0.12)ab	1.48 (0.19)ab
Compost B + Fert	171.39 (13.62)d	4.88 (0.77)e	0.89 (0.07)a	1.88 (0.27)ab

WA - systems trial

Gross N mineralisation rates were significantly higher in compost and clay amended plots than in control plots however there was no significant differences between compost and clay plots and the compost only amended plots nor between the compost only and control plots (Table 6.2). The ratio of gross N mineralisation/MB-N was highly variable and not significantly different between treatments (data not shown). The net rates of N mineralisation were not significantly different between any of the treatments (Table 6.2).

Table 6.2. WA Systems trial: Letters denote significant differences between treatments at $p < 0.05$. Numbers in brackets are standard error of the means

WA Systems trial	CO_2-C rate	Gross N min	Net N Min
	Mg^{-1} kg^{-1} d^{-1}	mg^{-1} kg^{-1} d^{-1}	mg^{-1} kg^{-1} d^{-1}
Control	1.41 (0.29)a	2.21 (0.62)a	0.75 (0.08) a
Compost	8.02 (0.69)b	4.37 (1.15)ab	0.94 (0.18) a
Clay + compost	9.89 (1.18)b	6.36 (1.39)b	0.75 (0.12) a

Microbial diversity - Catabolic Response Profiles (CRP)

WA - systems trial

The response of the active microbial population to the decomposition of organic substrates varied with treatment and with organic substrate type (Table 3).

Table 6.3. Letters denote significant differences between treatments at $p < 0.05$

WA Systems trial	Carbolic acid	Amino Acid	Amines	Carbohydrate	Aromatic compound
Control	0.98 (0.06)a	0.5 (0.04)a	2.73 (0.24)a	3.45 (0.28)a	1.26 (0.10)b
Compost	1.06 (0.03)a	0.73 (0.03)a	1.3 (0.16)b	1.47 (0.17)b	2.76 (0.39)a
Clay + compost	1.11 (0.02)a	0.82 (0.03)b	0.48 (0.08)c	0.53 (0.11)c	3.41 (0.37)a

The catabolic diversity of the microbial population when assessed by the Simpson-Yule index was low in all treatments and not significantly different (range 10 to 13). However, canonical analysis on standardised organic substrate response data was able to distinguish between the treatment groups with 87 per cent of the variation explained within factor 1 and 2 (Figure 6.2) indicating a difference in the response of the microbial populations within each treatment.

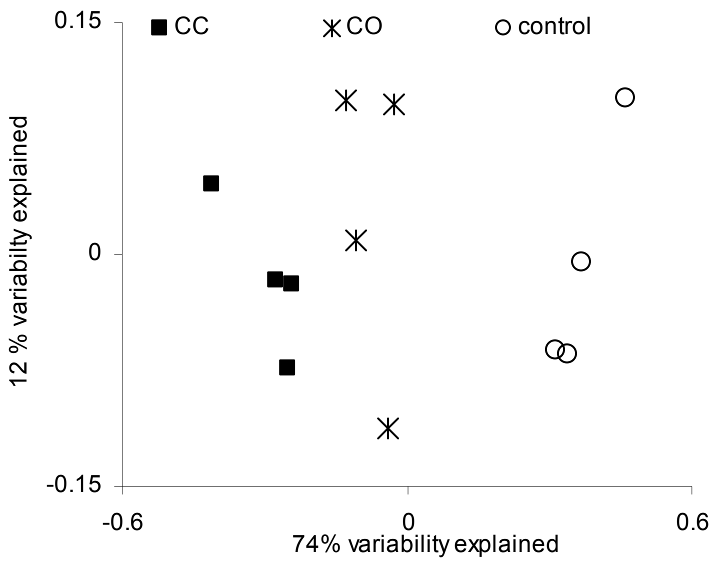


Figure 6.2. Results of canonical analysis of microbial diversity for WA Systems Trail. CC = compost + clay, CO = compost only plots.

Microbial biomass and activity

WA - N fertiliser replacement trial

Microbial biomass C (MB-C) levels were low (< 120 mg C kg^{-1}) initially in all treatments. Levels were generally higher at harvest than at planting. In all treatments the size of the microbial biomass increased over the length of the trial, this increase was not significant in control plots however it was for amended plots. There was no difference in the trends of MB-C levels between the low rates of compost A and compost B, however there was at the higher application rates (Figure 6.3).

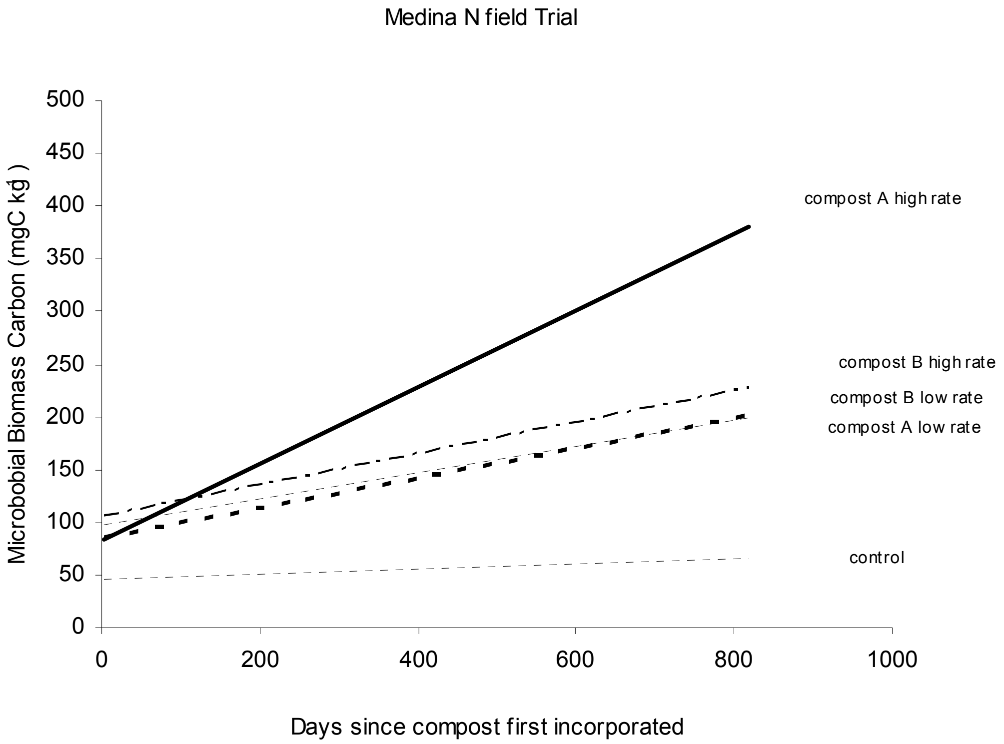


Figure 6.3. Microbial biomass C trends from WA Fertiliser replacement trial.

The trends in microbial activity as measured by CO_2-C production increased over time in all amended plots however it decreased for the control plots (Figure 6.4). At harvest of the final lettuce crop in the N replacement trial there were significant differences in the levels of MB-C between treatments ($F = 67.9$, $p = 0.00$, $n = 23$) with plots receiving compost A having a higher rate than compost B plots which had a higher rate than non-amended control plots (Table 6.1). Compost amended plots also had higher CO_2-C production rates than control plots (Table 6.1). There was no significant effect of fertiliser on either MB-C ($F = 0.011$, $p = 0.916$, $n = 23$), or CO_2-C rates ($F = 0.107$, $p = 747$, $n = 21$).

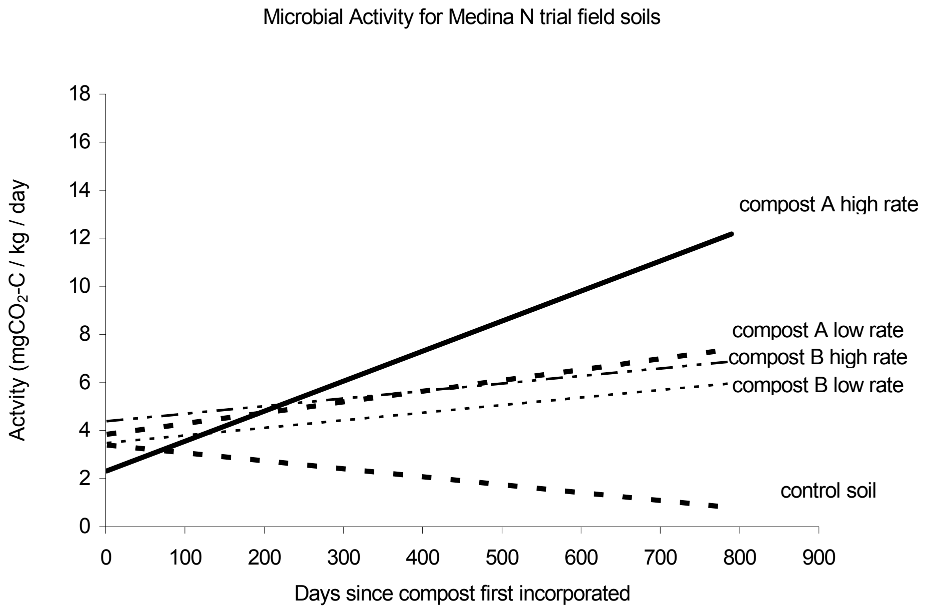


Figure 6.4. Trends in microbial activity as measured by CO_2-C production rates in WA fertiliser replacement field trial.

There was no significant difference in metabolic quotient (MBC/CO_2-C) between control and compost B plots and both were higher than plots amended with compost A. The microbial quotient (MBC/C org) was highest in soils amended with compost A followed by compost B and then the control soils, all were significantly different from each other ($F = 57.51$, $p = 0.00$, $n = 23$).

WA - systems trial

Initial microbial biomass measurements, analysed on soil collected 3 weeks after fumigation, were low and not significantly different between treatment plots (Figure 6.5).

After carrot harvest (149 days) MB-C in the compost plus clay plots were significantly greater than for the control and compost only plots. MB-C values in the compost and control plots were not significantly different for the duration of the experiment. MB-N levels were however significantly greater after the lettuce harvest (303 days) in the compost, and the compost plus clay plots compared to control soil. There was no significant effect of treatment or sampling period on the microbial biomass C: N ratio which when averaged was 6.85. There was no significant difference between treatments at any of the sampling times for the ratio MB-C/Total soil C or for MB-N/Total soil N.

At day 303, the compost plus clay and compost only treatments had significantly higher CO_2-C production rates compared to the control plots (Table 6.2). However, the metabolic quotient was not significantly different ($P = 0.18$, $F = 2.14$, $n = 4$) between treatments (data not shown).

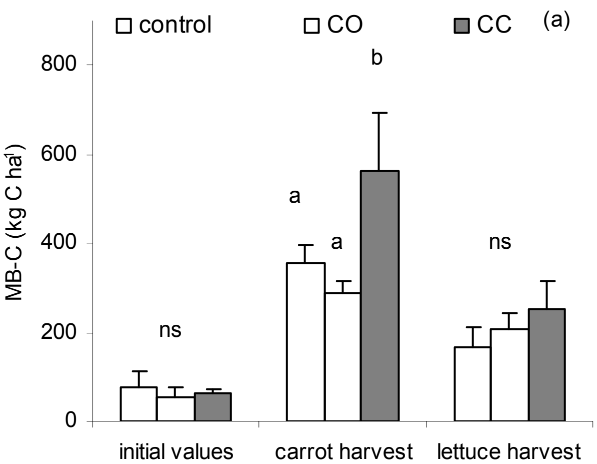


Figure 6.5. Microbial biomass C (MB-C) and microbial biomass Nitrogen (MB-N) levels in field soils from WA Systems trial. Bars indicate Standard error. CC = compost and clay CO = compost only amended plots. Control = non-amended soils.

Victoria - fertiliser replacement trial

The levels of MB-C were higher in compost amended plots than the control plots however these differences were not always significant (Table 6.3). At a constant inorganic N rate the CO_2-C production rates were lowest in control plots and highest in plots amended with the high rate of compost A. There was no difference between the low rates of compost A and compost B. The high rate of compost B resulted in low activity levels, not significantly different to the control plots (Table 6.4).

Table 6.4. Victorian fertiliser replacement trial: Different letters denote significant differences between treatments ($p < 0.05$), numbers in brackets indicate standard error of the mean

Vic. fert. replacement trial	Microbial Biomass C	CO_2-C rate
	mg kg^{-1}	mg kg^{-1} d^{-1}
Control	234.1 (20.9)a	6.58 (3.01)bc
Control + Fert.	225.6 (10.2) a	0.87 (0.27)a
Compost A (Low rate) + Fert.	339.0 (38.6)abc	3.65 (0.17)abc
Compost A (high rate)+ Fert.	410.3 (46.9)bc	7.22 (1.27)bc
Compost B (low rate)	310.84 (22.5)ab	2.64 (0.26)ab
Compost B (low rate) + Fert.	300.36 (37.0)ab	3.83 (1.86)abc
Compost B (high rate)	362.9 (53.7)bc	6.56 (1.65)bc
Compost B (high rate) + Fert.	390.6 (42.6)bc	1.98 (0.32)a

At constant inorganic fertiliser rates, the metabolic quotient was lowest in compost A amended plots and highest in the control plots. The effect of inorganic fertiliser on CO_2-C production rates varied with the different types and rates of compost addition and further analysis of data from this experiment is currently being conducted.

Discussion and conclusions

Microbial biomass and activity

The results of the incubation and the three field trials indicate benefits to soil microbial populations from amending soils with compost and/or compost and clay. An increase in C from the addition of compost amendments represents an increase in microbial food source that is able to support and maintain biological populations and their activities within the soil.

The microbial availability of the Carbon in the amendments influenced how quickly it was broken down in soil. Composted products that have already had much of the microbially available C consumed as part of the composting process, were more stable and better able to contribute to the long term build up of SOM than the poultry manure or partially composted grape marc. These results are in agreement with other studies (Bernal *et al*. 1998a, 1998b).

The MB-C levels were generally higher in compost amended soils than control coils for both field and laboratory experiments. Levels were comparable between compost amended field soils from the Victorian and WA sites indicating factors other than soil type are influencing microbial populations.

Values in the compost and clay amended soils in the WA systems trial and the high rates of compost in addition to N fertiliser in the WA N replacement trial are similar to those reported by Wells *et al*. (2000) for a similar 'environmentally managed' vegetable system on sandy soil. Those reported for 'best market potential' management and agricultural management were similar to the MB-C values found in the WA systems trial for the composted and the control plots and the composted plots for the WA fertiliser trial. Non-amended plots in the WA fertiliser trial were very low compared to other published data.

CO_2-C evolution rates were generally higher in the amended plots as has been found by other studies (Crecchio *et al*. 2005; Flavel *et al*. 2005). The highest activities were reported in WA fertiliser replacement trial in plots amended with compost A. This is a less mature compost than compost B and likely contains more readily available substrates for microbial decomposition (Flavel and Murphy, submitted).

The microbial quotient (MBC/C org) is useful for comparing soils with a range of different C contents and avoids the problems of working with absolute values such as MB-C or total C however there is no defined number that is considered healthy (Sparling, 1997). Microbial quotients are expected to decrease in soils where organic carbon is being exploited and microbial biomass pools will decline faster than total C (Sparling, 1997). For ecosystems in early recovery from a stress the reverse is true and the MB-C tends to represent a higher proportion of the total C. The significantly higher microbial quotients for the carrot crop in WA systems trial as compared to the initial values for the lettuce harvest could suggest a population in early recovery from a stress (such as physical soil disturbance during the carrot harvest).

The effects of agricultural practices, such as tillage and fertilisation, on the metabolic quotient are often inconsistent (Gupta *et al*. 1994; Wardle and Ghani 1995).

An increase in metabolic quotient (qCO_2) has been interpreted as a response to soil microbial populations to adverse conditions (e.g. a disturbance or a stress), (Insam and Domsch 1988; Anderson and Domsch, 1990; Graham and Haynes, 2005; Williams and Haynes, 1997). An increase in qCO_2 can also indicate an increase in microbial efficiency (Wardle and Ghani, 1995) or an increase in microbially available substrate activating the population (Sparling, 1997). Given the higher activities in the amended soils as measured by our N mineralisation rates, (microbial diversity in the WA systems trial) and CO_2-C production rates, we interpret the higher qCO_2 in the amended soils of both WA trials as a response to one of the following: Either an increase in microbial diversity (as indicated by CRP's in the WA Systems Trial) has resulted in a greater efficiency in the microbial soil community of amended soils or there is more available substrate in the amended soils. This additional substrate available for microbial consumption may stem directly from the addition of compost or indirectly due to increased root exudates as a result of increased plant growth in field experiments.

Microbial diversity

There are no published CRP's for Australian data. Previously reported CRP's from temperate systems indicate vegetable production systems have lower catabolic evenness values, than other land uses with values around 17 out of 25 substrates (Degens *et al*. 2000). These values are much higher than those found in the current study (10-13) as they are on clay and loam soils and in a very different climate to that of Western Australia.

Lower catabolic evenness, based upon CRP's has been linked to declining levels of organic C (Degens *et al*. 2000; Degens, 2001), our results support this with the amended soils having higher CRP's and C contents than our control soils. The lower values in our study may also be a result of the recent applications of pesticides, including fungicides, nematacides, and fumigation with Metham Sodium. Other studies investigating the effect of composted amendments on microbial functional diversity (using PLFA techniques) and enzymatic studies report no significant differences between the structure of microbial populations (Crecchio *et al*. 2004). However they do report application of these and other chemicals that effect soil organisms is common practice in vegetable production (Wells *et al.* 2000).

While it has not been confirmed that changes in community structure and catabolic diversity result in changes to soil processes and/or contribute to resistance to stress or disturbance, it is suggested we adopt farming practices that preserve or restore bacterial functional diversity rather than practices that diminish it (Bucher and Lanyon 2005). The results of the current work suggest amending soils with clay and compost does that.

N mineralisation rates

Gross N mineralisation rates were higher in amended compared to control soils in all experiments Rates in the WA systems field trial were higher than those found in laboratory incubation studies using soils from the same site (Flavel *et al*. 2005). MB-C, MB-N, and CO_2-C rates are also higher and most likely a result of root exudates and different microbial populations in the field soils as compared to incubated soils. Gross N mineralisation rates reported here are in the range of those reported for pastoral soils (Mishra *et al*. 2005).

Where gross N mineralisation and immobilisation rates almost equalled each other (e.g. within the WA systems trial) there is no significant difference in the net mineralisation between treatments. However, as N is cycled within the soil system it is continually being transformed into and out of plant available forms. The higher levels of N in the lettuce leaves of plants in the compost and clay treated soils were better able to take up some of the N as it was cycled between the pools.

To summarise the amended soils generally had a larger and more active microbial population as indicated by MB-C, MB-N and CO_2-C production rates and the Gross N mineralisation rates show this equates to a higher level of N cycling. Composted products result in a longer term more sustained release of both C and N than from manures. This reduces risks of N leaching from products such as poultry manure when much of the N is released before the plants are large enough to benefit from it.

Results were not as conclusive on the heavier Victorian soils and further analysis is currently underway on that data set to examine interactions between soil physical and chemical and microbial properties. While further studies would be useful to assess soil microbial populations under different types of crops, the results to date are promising and indicate that compost and clay amendments have the potential to improve biological soil properties vital for sustainable vegetable production in Western Australia and similar environments.

Appendix 6.1. PhD Progress Summary **19 September 2005**

Student: Tamara Flavel

Supervisors: Dr Daniel Murphy
Prof. Lyn Abbott

Chapter	Gross N fluxes and microbial population dynamics in coarse-textured soil after the addition of organic amendments	Data analysis completed	Analysis/write up completed (%)
1	Introduction and literature review.	na	100
2	Gross N mineralisation rates after application of composted grape marc to soil.	100%	100: Paper published 2005
3	Carbon and nitrogen mineralisation rates after application of organic amendments to soil.	100%	100: Paper in press
4	Repeated field applications of green-waste based compost increased soil biochemical properties and lettuce yield.	100%	100
5	Influence of compost and clay amendment on soil biochemical properties, community level physiological profiles and lettuce growth.	100%	100: Paper submitted
6	Conclusions and future work.	na	100

Publications

Flavel, T.C. (2002). Compost use in horticulture. Soils Are Alive Newsletter, October 2002.

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Flavel, T.C., Lalor, B.M., Murphy, D.V. and Fillery, I. (2005). Gross N mineralisation rates after application of composted grape marc to soil. *Soil Biology and Biochemistry* **37:** 1397 1400.

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Conference presentations

Flavel, T.C., Murphy, D.V., Abbott, L.A. and Paulin, R. (2001). Compost use in horticulture. Australian Soil Science Society Conference, Perth. December 2001. (Poster.)

Flavel, T.C. 2001. Compost research in WA: The soil biological perspective. Waste and Recycle Conference. Perth, November 2001. (Oral delivered by T. Flavel.)

Flavel, T.C., Murphy, D.V., Abbott, L.A. and Paulin, R. (2001). Compost use in horticulture, Biological Implications. IUSS Bangkok, Thailand, August 2001. (Poster.)

Flavel, T.C. and Murphy, D.V. (2003). Compost use in vegetable production: impact on gross N fluxes and implications for sustainable management practices. 12th N Workshop, September Exeter, UK. (Poster presented.)

O'Malley, P., Paulin, R., Wilkinson, K. and Flavel, T. (2003). Use of compost in vegetable production. Proceedings 4th International conference of ORBIT Association on Biological Processing of Organics, pp. 304-316, Perth. April-May 2003. (Oral delivered by R. Paulin.)

Paulin, R., O'Malley, P., Wilkinson, K. and Flavel, T. (2004). Carbon based horticulture and sustainability. AuSHS Conference, Harnessing the Potential of Horticulture in the Asia Pacific Region, 1-3 September, Coolum, Queensland *(Submitted to ACTA Horticulturae)*.

Flavel, T.C. (2004). 'Organic Amendments in Horticulture', Lecture for Soil Systems 3rd and 4th year students, 1 June. The University of Western Australia.

Flavel, T. (2004). 'Soil Health: impacts of compost on organic matter and soil biology', *Compost stakeholders meeting* 23 June. Perth, Australia.

4th year lectures

2004 Compost use in Horticulture. To final year organic agriculture students at UWA.

2004 Demonstration classes. To second year soil science students. Viewing UWA compost trials and discussing compost uses for broad acre and horticulture.

Conference attendance

Waste and Recycle, Perth November 2001.

!7th World Congress of Soil Science, November 2001 Bangkok, Thailand.

12th N Workshop, 22-24 September 2003. Exeter, United Kingdom.

Organics Symposium, May 2004. Perth, Australia.

SECTION 7 – TECHNOLOGY TRANSFER AND COMMUNICATION

Introduction

The aim of the projects technology transfer program was to promote identified benefits of using compost in vegetable production on light and heavy soils, and to develop and promote awareness of the requirements of vegetable production amongst the compost industry and the waste management industry.

The project's outputs are underpinned by the communication plan that was completed in February 2001. The communication plan focused on the production of extension materials (e.g. articles in industry magazines, fact sheets), presentations to the composting and vegetable industries at field days and meetings and the provision of advice to compost producers and growers. Building grower confidence in the use of compost has always been an important aim of these activities.

The target audience has been vegetable growers, compost producers and the organic waste management industry, and the key messages have been delivered via grower sites, media articles, field days, grower meetings, seminars and published material. This has included progressive results as the benefits of composted soil amendments to vegetable production have been identified. These have included:

- Improvement to productivity by increasing marketable yield and reducing fertiliser as well as potentially, irrigation and pesticide requirements.
- Critical quality requirements for vegetable production and the need to produce compost using auditable quality management programs.
- Compost's role in developing soil organic matter in vegetable production that can result in improved soil conditions and increased crop performance from improved soil quality, reduced soil erosion and improved efficiency of fertiliser, irrigation and potentially pesticide.
- Potential to address environmental issues associated with vegetable production including nutrient, and particularly nitrate nitrogen loss to ground water.
- Strategies for maximising benefits of compost use.
- Contributions to "safe, clean food production by reducing fertiliser, irrigation and in the longer term, pesticide use"; and
- The importance of the waste collection process delivering source separated organic materials to the compost industry in order to minimise contaminant risks and maximise potential compost quality.

Methods

Key stakeholders have been encouraged to contribute to management of the project. In Western Australia a project management group comprising three growers, two compost producers, the Vegetable Industry Development Officer, the PhD student based at the University of WA the state Horticulture Australia representative and the principal project officers that met al least twice a year.

Interstate coordination was managed with six monthly meetings between the state project teams and a senior HAL program representative. These alternated between Perth and Melbourne for the first two years of the project and subsequently, opportunities were available to ensure ongoing face to face communication in conjunction with conferences and other events.

The PhD program was managed through regular meetings between the project staff and thesis supervisors at the University of Western Australia.

Vegetable industry communication has been through State Vegetable grower Associations, Industry magazines, Field days, rural press and industry events and Expos. The establishment of several ‘Key grower sites’ was considered important for:

- promoting and encouraging greater use of compost in the vegetable industry; and
- validating findings from the research program.

The development of information packages was the other key component of the technology transfer process. The elements of this included:

- strategies for using compost and maximising results;
- information on potential benefits including fertiliser savings;
- facts on the production of compost suited to use in vegetable production; and
- options to improve soil organic matter management.

Communication with the Waste Management and the Compost Industry has been the other and arguably at least equally important focus. Recognising that the composting industry is still in its infancy, this has included active involvement and where appropriate, leadership in the development of the organic sector of the Waste Management Industry.

The underlying objective of all communication with the Organic Waste management sector has been to:

- developing and promoting compost quality requirements for vegetable production; and
- promote the requirements for achieving that quality throughout the waste management industry from compost process management and waste collection.

Communication has also targeted tertiary institutions and students involved in vegetable production and soil management. These have included the Soil Science group at University of Western Australia (the project has funded a PhD program that is supervised by this group), the Centre for Organic waste Management at Murdoch University and Gilbert Chandler College (University of Melbourne), Werribee.

Other identified ‘groups’ have included:

- organic as well as biological farmers associations;
- State waste management bodies/board and EcoRecycle Victoria; and
- key resource management agencies including water commissions, environmental protection and planning.

Every opportunity has been taken to promote the project and its results including the potential benefits and synergies for all sectors of our community that arise from the reuse of organic wastes in vegetable production. This has included presentations at national and international conferences and several interstate events.

Results and discussions

The outputs of the technology transfer program have principally targeted the vegetable and organic waste management industry. They are detailed in the Appendix 7.1 under the headings:

- Media, radio, press, newsletters and magazine articles.
- Vegetable grower communication – field days, tours, expos and displays.
- Other stakeholder meetings and presentations.
- Conferences, seminars, workshops, papers and presentations.
- Planning meetings.

The concept of 'Carbon based production' has developed from the recognition that soil organic matter and the associated recycling of organic materials is the basis for most if not all of the potential benefits from using compost. This has become the basis for a number of national 'roadshow' programs that have targeted growers and the organic recycling industry stakeholders during the life of this project. These included:

- Three seminars in Sydney, Hunter Valley and Orange as part of an Agriculture Action Agenda program held in mid March 2002.
- A series of two seminars and one field day on 'Bullet proofing soils' that promoted the use of compost in vegetable and other forms of horticultural production that were held in Melbourne, Seymour and Tatura in Victoria and to a Seminar in Adelaide during March 2004; and
- Presentation of project findings to the 'Compost – the way to grow' two day seminars that were held in Melbourne and Perth during February and March 2005. CD's of the various programs are available from the Waste Management Association from admin@wmaa.asn.au.

Vegetable industry

Initial communication focussed on promoting the project and its objectives to the vegetable industry through the media and various events. These included making presentation to industry field days such as carrots and lettuce programs at the Medina Research Station, Because of a combinations of clashes with other events, difficulties with coordinating the timing with suitable crop development stages and perceptions, real or otherwise that there would be insufficient interest, specific events for vegetable growers at either the Medina Research or demonstration sites were not held.

A compost demonstration trial was established at the Werribee Expo in May 2003. The trial was 8 beds wide and 18 metres long and was planted with broccoli after compost was incorporated. Three locally produced composts were included in the trial at 3 different rates, as well as a treatment that did not receive any compost application (control). The trial could have been better located to maximise exposure but nevertheless generated interest amongst some growers. At the trial site a display was also set-up to demonstrate what the compost products looked like on the ground at different rates and what the approximate costs of application were. A display with brochures and posters was also set-up in a tent near the trial site.

A series of fact sheets were prepared for vegetable growers. Growers are sceptical of the many claims that are made of soil amendment products such as composts. The fact sheets were developed to provide growers with enough information to 'demystify' compost and be able to make informed decisions about the value of such products.

A major issue for achieving greater use of compost relates to realising that while the benefits of using compost are all positive, the improvement in returns are usually too small to warrant the changes involved with using it.

There is increasing awareness of the importance of soil health and organic matter management among growers. This has been clearly evident in our small group and one-on-one discussions with growers. It is also emerging as an important strategic issue at the whole of industry level (soil health was listed this year as a priority in the R&D strategies of the vegetable and potato industries). The Environmental Management Systems that are being developed for horticultural industries around Australia will lead to more sustainable practices being adopted by growers, and from our results, they will benefit from including the use of compost.

> The development of Environmental Management Systems for horticultural industries around Australia focuses on more sustainable practices being adopted by growers. These outcomes will be improved by including the use of compost.

A half day seminar for vegetable growers in the vegetable growing regions around Perth was attended by around 40 growers in October 2003 and further events will be held when strategies to overcome some of the factors that limit compost use are able to be implemented.

The recent National Compost roadmap project, funded by the Waste Management Association of Australia, various State Environmental Agencies through their waste management bodies including the WA Waste Management Board and EcoRecycle Victoria, and the Commonwealth Government through the Barton Group, was a major event that attracted significant participation from the range of stakeholders targeted. Attendance at these two day conferences held in Brisbane, Sydney, Melbourne, Adelaide and Perth attracted between 75 and 140 delegates at each venue, however in all states, the participation by vegetable growers and farmers was disappointing.

This process will culminate in the release of a strategic market development plan in July 2005 as a 'blueprint' for developing the agricultural, and principally vegetable and other intensive horticultural industry groups as long term sustainable and critically important markets for composted organic wastes from both rural and urban community.

The disappointing attendance by vegetable and other growers needs to be kept within the context of progress to date with recycling/reusing organic wastes. In reality many agricultural wastes are being reused and developing markets for urban organic wastes has been hampered by the lack of appreciation of what is required to develop the horticultural market.

This National 'Compost Roadmap Project' in itself is arguably the first significant acknowledgement that the horticultural and vegetable industries in particular, have a major role to play in driving the reuse of organic wastes to land application.

Compost use in vegetable production faces significant competition from the current largely uncontrolled use of raw organic materials.

The current situation with limited growth in the vegetable industries use of compost is hardly surprising, given the time that it has taken the waste management industry to realise this potential, and the reality that the composted products they produce are 'relatively very expensive' compared to the widely available organic wastes, usually animal manure, from agriculture.

Waste management industry

The project has resulted in the development of a set of quality specifications for compost to be used in vegetable production that are based on the Australian Standards for 'Compost, Soil Conditioners and Mulches', AS 4454–2003.

When green wastes are used as a feedstock for composts destined to be used in the vegetable industry, process management involving passing the compost through a 10 to 12 mm screen before use has also been developed. These specifications are provided in Table 7.1 and the use of a 10 mm screen is preferred.

Table 7.1. Recommended critical analysis values for compost use in vegetable production. Analysis conducted to Australian Standards AS 4454–2003

Measurement	Value	Unit	Comment
Carbon Nitrogen (C/N) ration	< 20	none	For crop available nitrogen.
Nitrogen Drawdown Index (NDI)	> 0.5	none	Lower values likely to compete for crop N.
Organic matter	> 35	% DM	Higher the better.
pH ($CaCl_2$)	5-7.5		Ideally around 7.0.
Electrical conductivity	< 6.0	dS/m	
Toxicity (potting mix test)	> 60	%	Indicates immaturity and possibly anaerobic composting conditions.
Moisture content	> 25	%	Ideally around 40%.
Total Nitrogen	> 1.0	% DM	Generally not greater than 1.7%.
NH_4 + NO_3	> 100	mg/L	Also indicates N availability for crop.
NO_3/NH_4 ratio	> 0.14	(m/L)	High ammonium level indicates immaturity.
Particle size	< 12 mm	Screen mesh	10 mm screen preferred.

The carbon in wood is highly lignified and is therefore more resistant to decomposition in the initial decomposition phase of the composting process. The minimum 10 to 12 mm screening requirement is therefore aimed at removing undecomposed woody material and preventing the compost, or rather the microbes within the compost, from competing with crops for nitrogen during early crop germination and or establishment. Earlier work identified this problem (Paulin *et al*. 2001) and it was also recorded in one of the initial carrot trial at the Medina Nitrogen Replacement trial site.

This project focussed on using composts made from green wastes recognising that in the short term, this was the largest and cleanest organic waste stream available from urban sources. These wastes can also be derived from land clearing activities and with restriction on burning; these are an increasing feedstock for compost manufacture. This waste stream has an even higher content of wood than the typical green waste collected from street verges and council drop off centres and the need to manage potential problems associated with them is even more critical.

The importance of using fine screens was confirmed during the Tour of Californian compost production and utilisation (Paulin 2002) that took place during May 2002 and the use of fine screens has been widely adopted by producers that aim to produce compost for vegetable production.

> The Californians have facilitated agricultural reuse of urban organic wastes by:
> - mandating organic landfill diversion targets;
> - requiring compost producers to demonstrate compliance with minimum health safety standards for disease, pests, weed and heavy metals;
> - encouraging compost quality through a process of disclosure.

The Californian tour was unable to attract any vegetable grower participation; however the compost industry participants from all the mainland states witnessed a composting industry that has achieved the highest diversion of urban wastes into horticulture, principally vegetable production, in the developed industrialised world (Paulin 2002 – Report). It also provided opportunity to discuss some of the key aspects of legislation and policies that have underpinned this success.

These factors are discussed in the tour report, and included:

- Imposing substantial financial penalties for not meeting organic waste diversion targets.
- Requiring compost producers to demonstrate compliance with minimum safety standards for disease, pests, weed and other contaminants including heavy metals and a range of bio-toxins; and
- Encouraging participation in quality assurance programs that include a requirement to disclose minimum levels of product information and analysis.

With respect to the composting industry, we have continued to promote best practice compost production. Project members have been actively involved in the development and with carrying out a range of executive roles in Compost Industry groups including Compost Victoria and the Compost Industry Association of Western Australia. More recently a workshop organised in conjunction with the recent WA Waste and Recycle 2004 Conference in Fremantle resulted in the establishment, of a recycled organics group (ROWA, Recycled Organics WA) as a sub-group to the Waste Management Association. With potential membership of all stakeholders involved in the recycling and reuse of organics, this group has much wider stakeholder representation than the previous Compost Industry Association and will continue the affiliation with the National Compost Australia group.

The objective to promote the development of appropriate compost products based on quality requirements of vegetables and other crops has also been served by membership on the Australian Standards Committee for Composts, Soil Conditioners and Mulches, AS4454 (K. Wilkinson). Through this we have had direct influence on the development of the Australian Standard (AS4454), particularly with regard to best practice processing guidelines. Although at the moment it is not a market-driven Standard, we hope to influence development in that direction as more fit-for-purpose products are developed. This will involve the development of guidelines for producing a range of compost products that are suited to different uses, the emphasis being on providing guidance, not specific standards.

Extensive presentations have also been made to all targeted stakeholders including universities, and a number of papers and posters have been presented throughout Australia and overseas to a range of audiences from compost producers and waste management industries, government resource management and planning and researchers in horticulture and soil science.

Appendix 7.1 lists most of the presentations made to stakeholders and to various conferences. Some examples include the presentation of 2 oral papers at the 2002 International Symposium on Composting and Compost Utilisation in Columbus, Ohio in May 2002. One paper focussed on preliminary findings from this project. These results were discussed with the underlying assumption that compost use will be the building block for economically, environmentally and socially sustainable 'carbon based horticulture'. It was noted that composts derived from urban green waste usually require longer processing times than is currently practised, in order to provide consistent short-term benefits to vegetable production. The importance of compost quality and its likely impact on the acceptance of compost in horticultural industries was the subject of the second paper. It showed that green waste compost in Australia is highly variable in quality and argued that the adoption of market-based quality assurance programs was a necessary precursor for achieving consistent performance with compost in horticultural applications.

Products and tools

The project has produced a number of published information products that include:

- A series of four fact sheets on compost for vegetable growers covering 'What is compost; What use is compost; Getting started and Choosing a supplier.
- A draft bulletin on 'Compost production and use in horticulture – this has been regularly updated and has been available since early 2000, as a general source of locally relevant information on producing and using compost. It will be finalised and published as an official bulletin on completion of this report.
- A 'Note on Compost use in Horticulture' produced as a single page handout for industry expos.
- A discussion paper 'Compost production for agricultural use – issues for the developing recycled organics industry' has been finalised and reflects the considerations of this project and other work with a range of horticultural crops.

These are attached to this report.

When completed, the information compiled and various products will be embedded into a 'Compost Page on the Department of Agriculture's web site. With further development to make them user friendly, several excel based spreadsheets will be made available for use by growers, consultants and the compost industry. These potentially include:

- A vegetable fertiliser model – a tool for adjusting grower fertiliser programs to accommodate the use of composts. It will integrate soil analysis information, cost the use of compost based on fertiliser savings, associated application costs, and other anticipated changes to returns and management costs. It will also enable programs to be compared with established industry best practice.
- Gross margin vegetable crop calculator to compare likely impacts of compost rate and cost together with management cost savings and yield improvements and returns. This model was used to derive Table 9.1 that indicates yield improvements necessary to cover costs of compost application for the crops grown at the System site trials at the Medina Research Station;
- Compost application cost calculator that has application to annual (vegetable) and perennial crops.

Appendix 7.1 Project VG 990016, Technology transfer and communication outputs

Activity	Audience	Date	Key message
Media – radio, newspapers, newsletters and magazine articles			
ABC Country Hour Interview	Rural community	Sept. 2000	Albany seminar
		Nov. 2001	Compost project
		Nov. 2001	Compost, its availability to farmers
		Nov. 2001	Benefits of compost
		Jan. and Feb. 2002	Promoting Californian tour
		June 2002	Californian tour and compost 2002 conference outcomes
		Aug. 2002	Project progress and establishing
		ABC policy change has resulted in its use restricted to event announcements	
Good fruit and vegetables	Fruit and vegetable growers	Dec. 2000	Introducing the project
		Mar. 2001	Introducing the project
		May 2002	Improving soil with compost
Countryman Rural paper	Growers	Oct. 2000	Articles on project
		May 2001	Articles on project
		Nov. 2002	Project progress and grower site establishment
Westralian – weekend supplement	Community	Feb. 2001	Compost – clean food and organic reuse
BioCycle magazine	Composting industry, Australia and international	July 2002	Introducing the project
		Aug. 2002	Benefits of quality compost and quality assurance
Article in sHORTs newsletter	NRE officers	Sept. 2002	Introducing compost
Com-Post (an IHD project newsletter)	Compost producers; Local Govt.; Consultants	Aug. 2001	Research update
		Oct. 2002	Research update
Compost Seminar – Albany	Compost producers; Local Govt.; Consultants; growers	Sept. 2000	Production and benefits of compost
WA Vegetable Grower	Vegetable growers	Mar. 2001	Introducing the project
		Nov. 2002	Project progress and grower sites
		Oct. 2003	Project progress
Victorian Vegetable Grower		Mar. 2001	Introducing the project
Victorian Vege-Link newsletter	December 2001	Dec. 2000	Introducing the project
		Mar. 2001	

Appendix 7.1 continued …

Activity	Audience	Date	Key message
Vegetable grower communication – field days, tours, expos and displays			
SW Development Corporation	Growers and organic recyclers	Nov. 2000	Benefits of compost – Manjimup
			Donnybrook and Harvey
Manjimup Horticultural Expo	Growers and community	Nov. 2000	Introducing the project
Melbourne International Flower and Garden Show	Horticultural industries	Apr. 2001	Presentation on benefits of compost and quality assurance
Seymour Alternative Farming Expo	Rural community	Feb. 2001	Display and brochures on benefits of compost
		Feb. 2002	
Werribee Expo		May 2001	Display and brochures on project and benefits of compost
Young Werribee growers group	Vegetable growers	July 2001	Introducing the project; research update
Field day presentation, Gippsland	Various growers	Nov. 2001	Benefits of compost and mulch; guidelines for application
		May 2003	Display, brochures and demonstration trial with compost
Carrot field day – Medina	Vegetable growers	Apr. 2002	Benefits of compost in vegetable production
		June 2003	Project progress
Californian Compost Tour	Compost industry and growers	May 2002	Production and use in horticulture
WA Vegetable Association	Peak industry group	Sept. 2002	Progress and future compost work
		Nov. 2003	Progress and future compost work
Carbon Based Horticulture – Agriculture Action Agenda	Growers, compost industry and Government	Mar. 2003	Benefits of compost – Sydney
			Hunter Valley and Orange
Vegcheque meeting	Vegetable growers	July 2003	Summary of project findings
Vegetable industry seminar	Vegetable industry	Dec. 2003	Compost in vegetable production
South Coast horticulture	Growers, vegetable and other	Nov. 2003	Compost progress
Roadshow – 'Bullet proofing soils'	Vegetable and other growers, composters and agencies	May-June 2004	Reporting project findings – Knoxfield
			Tatura
National Compost Roadmap project *'Compost – the way to grow' capital city seminar program*	Vegetable and other horticultural growers and general agriculture	Feb. 2005-Mar. 2005	Development the 'agricultural' market for compost

Appendix 7.1 continued …

Activity	Audience	Date	Key message
Other Stakeholder meetings and presentations			
Compost Victoria	Compost producers; Local Govt.; Consultants	Apr. 2001	Research update
		Sept. 2002	Californian tour
EcoRecycle Victoria	Financial stakeholder	Dec. 2000	Project reporting
		June 2001	
		May 2002	
		Sept. 2002	Californian tour
		Feb. 2003	Project reporting
WA Stakeholder meetings/seminars	Growers, local and State Government, Waste industry, compost producers, tertiary institutions	Nov. 2001	Project update
		June 2002	Project update at Murdoch COWM
		Nov. 2003	Project update
		June 2004	Project update
Compost industry presentations	Compost produces and Regional Waste Groups	Oct.-Nov. 2002	Five presentations on progress and future work
Conferences, seminars, workshops, papers and presentations			
Compost seminar – Albany	Compost producers; local Govt.; Consultants; growers	Sept. 2000	Production and benefits of compost
IHD Horticulture Conference	Researchers, horticultural industries	Sept. 2000	Poster and brochures on project and benefits of compost
Waste and Recycle Conference, WA	Compost producers; local Govt.; consultants	Nov. 2001	Benefits of quality compost and quality assurance
		Nov. 2001	Progress with project
		Nov. 2002 x 2	Compost marketing and carbon based production
		Sept. 2004	Economics of compost to vegetable growers; and
			Compost quality for vegetable growers
WA Waste Management Association	Stakeholders	Nov. 2000	Introduce the project
		Apr. 2001	Marketing issues for vegetable growers
		July 2001	Marketing requirements for horticulture
		Aug. 2003	Organic recycling

Appendix 7.1 continued …

Activity	Audience	Date	Key message
Conferences, seminars, workshops, papers and presentations *continued …*			
University of WA	4th yr Agric. Students	Mar. 2001	Compost project and funding opportunities
	Seminar for staff and post graduates	Sept. 2003	Project progress and R&D implications
	4th yr Agric. Students	May 2004	Value of organic amendments
	1st yr Agric. Students	Sept. 2004	Compost for sustainable vegetable production
Melbourne International Flower and Garden Show	Community	June 2001	Compsot production and benefits use
Werribee Young Growers	Vegetable industry	June 2001	Project and benefits of compost
Baileys fertilisers	Fertiliser producers	July 2001	Marketing compost to vegetable growers
Seminar on composting, Tatura	NRE officers and growers	Feb. 2002	Benefits of quality compost and quality assurance
'Rural Waste Management Issues' seminar presentation, Bendigo	Local Government; composting industry	Aug. 2002	Benefits of quality compost and quality assurance
Curtin University lectures	2nd Viticulture students	Sept. 2002	Role of soil organic matter
		Sept. 2003	Role of soil organic matter
Seminars on compost and organic waste management	Local Government, composter's and growers	Nov. 2002	Morwell, Gippsland
		Nov. 2002	Bairnsdale, Gippsland
International composting conference, Ohio, USA	Researchers	May 2002	Paper on the Compost project
			Paper on the Compost quality and performance in horticulture
Compost stakeholder workshop	Local Government; Govt., composting industry; growers	Oct. 2002	Murdoch COWM – directions for R&D
'Greening Gippsland' seminar presentations at Morwell and Bairnsdale	Local Government; Composting industry; growers	Oct. 2002	Benefits of quality compost and quality assurance
Presentations to EcoBuy Alliance meetings	Local Government in Melbourne and Shepparton	Nov./Dec. 2002	Benefits of quality compost and quality assurance
Compost workshop	Organic recyclers	Nov. 2002	Basic requirements for compost production
WA Waste Management Board	Ministerial advisory body	Aug. 2002	Project progress and issues for marketing compost
State Water Foundation	Premier Advisory Council	Feb. 2004	Compost, soil management. Horticulture and water management

Appendix 7.1 continued …

Activity	Audience	Date	Key message
***Conferences, seminars, workshops, papers and presentations** continued …*			
Seminar on role of compost in horticulture	Compost Industry, Government and agencies	June 2004	Reporting project findings – Compost SA WAITE Institute staff
Australian Society of Hort. Science	Institutional and industry	Sept. 2004	Role of compost and vegetable production in sustainability
SE Metropolitan Regional Council	Regional waste management	Dec. 2004	Project update PhD progress
Murdoch Thailand project	Project members	Mar. 2005	Vegetable compost project
Sustainable waste management	Ministerial advisory group	Apr. 2005	Vegetable production links to sustainable waste management
Planning meetings			
Interstate planning	WA Dept. of Agric. And DPI Victoria	Nov. 2000	Coordination
		Mar. 2001	Coordination and progress
		Nov. 2001	Coordination and progress
		June 2002	Coordination and progress
		2003-2005	Continued less formal contact
WA Project Management Group	Stakeholder representatives	Nov. 2000	Introduction to project
		June 2001	Progress reporting
		Sept. 2001	Progress reporting
		Feb. 2002	Progress reporting
		July 2002	Progress reporting
		Nov. 2003	Progress reporting
		Apr. 2004	Wrap up R&D program
PhD program coordination	Dept. of Agric. and University of WA	Oct. 2000-June 2001	Three meetings
		Sept. 2001-June 2002	Four meetings
		Aug. 2002-May 2003	Three meetings
		Sept. 2003-Mar. 2004	Two meetings
		Nov. 2004	Regular contact, paper reviewing for PhD

SECTION 8 – OVERALL PROJECT DISCUSSION

With the focus on increasing vegetable productivity, the project was established to:

- Quantify benefits and develop strategies for maximising the benefits of compost use to vegetable production; and
- Identify issues that limit the development of vegetable production as a market for composted urban and agricultural wastes.

The benefits of compost include improved marketable yield, savings in fertiliser costs and a range of other savings including reduced irrigation and harvesting costs that are situation dependant. With continued use, a range of improvements to soil quality and fertility contribute to further savings in fertiliser use as well as more consistent reductions in irrigation and potentially, reduced pesticide use. These improvements to soil performance 'bullet proof' against the adverse impacts of management failure and unanticipated climatic events that have the potential to reduce production.

Considerable progress has been made however, achieving greater use of compost in vegetable production is constrained by its cost and in particular, its lack of competitiveness with other organic amendments, namely manures.

The results of this project have been extensively reported and formed the basis of our input to the recently concluded National Compost Roadmap Project that was established to provide a strategic plan for the development of the compost market, primarily in agriculture.

Benefits of compost use to vegetable production

Productivity

The over whelming conclusion from our work is that growers can anticipate positive improvement in marketable yields and reductions in production costs associated with vegetable production. Compost quality is clearly important and to achieve consistent increased returns from using compost, it is important to make adjustments to their fertiliser use.

BENEFITS OF COMPOST

- ***Increased production and crop quality.***
- ***Significantly reducing inputs of fertiliser, irrigation and potentially pesticide use and;***
- ***Maintaining and improving soil and water quality.***

With regular compost use, improved productivity will largely result from the soils increased ability to supply plant available nutrients and moisture, and to reduce periods of stress during the life of the crop.

There are concerns relating to how well compost works with some crops. Leafy vegetable crops, including lettuce and Brassica, respond with greater consistency than root crops such as carrots and potatoes. However our work indicates that all crops will potentially benefit from compost use. Despite the repeated occurrence of poor quality in the compost applied to carrot crops the overall indication was for compost to improve carrot quality.

In order to achieve optimum yield certain crops such as carrots and potatoes appear to have a greater requirement for a "balance" to be maintained between the major nutrients. With this project, and with most of our compost work, it was not possible to adequately adjust fertiliser rates for the nutrients supplied by compost and our results with carrots and possibly potatoes, indicate that closer attention in keeping, the major nutrients in particular, within reasonable balance is needed. This emphasises the need to adjust fertiliser programs to account for compost supplied nutrients and to monitor soil and plant analysis.

Fertiliser savings and compost contributions to crop nutrition

The fertiliser value of compost based on low cost common fertilisers such as urea, superphosphate and potassium sulphate will range from \$20 with the initial application to over \$30/m^3 with continued use. Using typical costs for compost and its contractor application rates, these potential savings can meet 50% to 65% of the applied cost of premium quality compost within a 50 to 100 km of the compost producer.

Fertiliser savings will cover at least ONE HALF to TWO THIRDS of the cost of applying compost.

Estimated fertiliser cost savings associated with compost use initially include allowance for 40 per cent of its phosphorus content to be equivalent to superphosphate (Figure 1.28) and 100 per cent of its potassium to be plant available.

PHOSPHORUS
Initially 40% of the phosphorus content of compost is equivalent to superphosphate and Standard Colwell phosphorus test effectively estimates crop phosphorus requirements in compost amended soils.

With continued application, all of the phosphorus from compost will contribute to the soil phosphorus pool and adjustments in fertiliser phosphorus requirements will be achieved through standard soil testing procedures. This is because the standard Colwell procedure based on bicarbonate extraction, that is used in Western Australia to estimate plant available phosphorus, continues to provide reliable estimates of sufficiency when soils are amended with compost (Figure 1.27).

POTASSIUM
Potassium from compost is 100% available from the initial application; and within three applications, improvements to cation exchange capacity results in a 20% reduction in potassium requirement.

Potassium use efficiency increased from around 15% following the initial application to 20% following a third application (Figure 1.34), with improvements to cation exchange capacity presumably contributing to these savings.

While not directly measured, our results also indicate that the magnesium content of compost is also 100% crop available.

MAGNESIUM
Compost magnesium is 100% crop available

Nitrogen is a complex issue because its availability is influenced more by compost quality and possibly biological activity than other major nutrients. Our work suggests that initially very little of the compost nitrogen was available and that at the conclusion of both the Nitrogen Replacement and System sites, around 18% was either utilised by the crop or leached (Table 3.38). However, with the final trial at the nitrogen site, the less mature compost (Compost A) produced significantly higher yields, presumably as a result of stimulating mineralisation of soil nitrogen reserves. It contributed the equivalent of 300 kg/ha of fertiliser nitrogen to the lettuce crop enabling 95% of maximum yield to be achieved with 267 kg/ha of applied nitrogen compared to 582 kg/ha for the control. It is generally accepted that nitrogen fertiliser application can be reduced by the equivalent of around 20% of the nitrogen contained in an initially application of compost and that this increases to around 30% with succeeding applications. Our work confirms that the utilisation of the stored nitrogen is dependant on compost quality and that over time, a very high proportion of compost nitrogen can be utilised by crops.

NITROGEN
Soil nitrogen reserves increase with continued compost use and with appropriate compost quality, result in significant supply of soluble nitrogen that have the potentially to reduce nitrogen requirements by up to 50% on sands.

The important result of organic nitrogen mineralisation within a healthy 'fertile' soil is that plant available nitrogen can be maintained during periods of rainfall that typically leach fertiliser nitrogen out of the crop root zone. A further important issue is that any surplus mineralised nitrogen can be re utilised by soil microbes. In this way, nitrogen losses can be significantly reduced and this process explains why ground water nitrogen levels under organic cropping systems have very low nitrogen levels (less than 10 mg/kg) compared to equivalent 'inorganic' farming systems (48 mg/kg) (Vogtmann presentation 2000).

Soil nutrient reserves are essential for sustained mineralisation. Our work has shown that regular compost application builds substantial nitrogen reserves in the top 30 cm of coarse sands when after five crops at the System site, levels were almost three times those in untreated soil (Table 3.33). Further, soil analysis indicated that levels of nitrate nitrogen in the soil solution, assuming field capacity conditions (10% volumetric soil moisture) was in the order of 200 mg/kg (Table 3.33). This level is the upper range of hydroponic system requirements and indicated compost increased soil nitrogen mineralisation early in the life of the crop. This supports the view that compost use can be used to reduce fertiliser nitrogen requirements and reduce its loss to groundwater. Leachate collections, without benefits from reduced nitrogen application support this (Table 3.40).

These findings suggest that with the continued use of compost further savings in fertiliser and in particular nitrogen use can be achieved, enabling nitrogen use efficiency to be increased and total application substantially reduced over present rates.

A compost maturity index developed in California has demonstrated that a relationship exists between compost quality (maturity) and nitrogen fertility in vegetable production (Buchanan 2002). This work has also shown that the crop nitrogen response is dependent on compost quality/maturity and indicates that the standards developed for compost nitrogen analysis provide a good indicator of its potential performance in vegetable production.

Irrigation savings

The system site allowed treatments to be independently irrigated. Recorded savings have been greatest for the clay plus compost treatment during the cooler Autumn to Spring period when natural rainfall makes a significant contribution to crop water requirements. While the addition of clay has further increased soil moisture holding capacity, results indicate that savings during the summer months when evaporative demand is highest, are considerably smaller. This presumably reflects the coarse nature of the sandy soils used and in particular the limited hydraulic conductivity that prevents crops being grown without daytime application of irrigation.

IRRIGATION
Compost significantly increases soil moisture holding in light sandy soils. While this study suggests that under conventional vegetable management, savings are unlikely to exceed 10% over a 12 month cycle more work is warranted.

Average irrigation savings over a 12 month period estimated from this work are likely to be greater than 20% for the compost plus clay treatment but less than 10% for the compost alone treatment. The automated triggering of irrigation using the same soil moisture tension setting across all treatments could have potentially reduced the indicated savings to irrigation (Table 3.42). More work in this area is warranted.

Soil quality, fertility and health

Our results have consistently identified the importance of soil organic matter in improving all aspects of soil quality and is a compelling reason for placing much greater emphasis on the management of soil organic matter in vegetable production and agriculture in general.

Soil quality: Measurements of soil quality that included Bulk Density, Cation Exchange Capacity, volumetric water holding capacity, pH, Organic Matter (Carbon) and nitrogen levels have all improved significantly with regular additions of compost at both the sandy Western Australian and heavy soil Victorian sites.

In coarse sands, soil carbon levels are known to plateau at low levels while in heavier soils they achieve much higher levels. However even in our coarse soils, significant increases that potentially contribute to carbon reserves and therefore the soils capacity to sustain the populations of microbes, micro fauna and organisms that collectively contribute to soil health, fertility and performance, were recorded.

> **SOIL QUALITY**
> **With regular compost use:**
> - **Bulk density is reduced, improving potential root growth, drainage and infiltration.**
> - **pH is buffered around 7.0**
> - **Cation exchange increases.**
> - **Soil moisture holding increases.**

The intention of investigating the potential for the addition of clay to allow soil carbon to exceed 1.0 per cent and to possibly approach 2.0 per cent was not realised, partly because the initial carbon levels, even by Swan Coastal Plain standards, were very low and secondly because only five crop cycles were completed.

At the conclusion of this project, 200 t/ha of compost was applied to the 'Systems' site as part of continuing work to quantify the longer term benefits of compost use. This will involve continuing production of vegetable crops using 30 m^3/ha over the next 12 to 24 months.

However achieving soil carbon levels that will sustain microbial population dynamics necessary to maintain soil nitrate nitrogen levels and to potentially manage soil pests and diseases are likely to require further changes to management practices that could include:

- Reductions in soil cultivation and the use of equipment that is less damaging to soil microbial populations and their contribution to soil structure.
- Greater emphasis on using safe pesticides and integrated pest management practices.
- Changes to crop rotations and more extensive use of cover crops.

Finally, with light soils in particular, increasing soil carbon above current levels will be critically important for increasing soil moisture holding capacities and their associated hydraulic conductivity to levels where day time irrigation, and the associated large evaporative losses, can be significantly reduced.

> **SOIL FERTILIY**
> - **Without the addition of compost, soil organic matter and carbon levels decline in all soils.**
> - **Compost use results in substantial organic nitrogen reserves and mineralisation has the potential to significantly reduce nitrogen fertiliser requirements.**
> - **Compost use reduces nitrogen leaching.**

Soil fertility is related to crop nutrient supply and includes minor and trace nutrients within which heavy metals are an important consideration. This is because of their potential to impact on soil quality and health, and to harm human, animal and crop health, as well as the environment.

Fertility is intimately related to improving and maintaining soil carbon levels. The major potential outcome from building fertility will be to improve nitrogen fertiliser management through the development of soil nitrogen reserves. Both the Nitrogen Replacement (Figure 1.43) and System trial sites (Figure 3.9 and Table 3.37) in Western Australia and the Nitrogen Replacement trial site in Victoria (Table 2.14) have demonstrated significant improvements in soil nitrogen reserves following compost application. The percentage improvements over control plots are summarised in Table 8.1.

Table 8.1. Comparison of increased soil nitrogen at planting of trials in Western Australia(% db) and Victoria (mg/kg)

Compost rate	Trial site and N°.	Total nitrogen		
		Control	Compost	% Increase
Compost 30 m^3/ha	WA; N Replacement - 7	0.027	0.048	77.8
Compost 60 m^3/ha	WA; N Replacement - 7	0.027	0.065	140.7
Compost 30 m^3/ha	WA; System site – 5	0.013	0.041	192.9
Compost 30 m^3/ha + Clay	WA; System site - 5	0.013	0.056	300.0
Compost 70 m^3/ha	Vic; N Replacement - 4	0.15	0.22	46.7

Soil analysis confirms that variable nitrogen mineralisation had taken place at the Western Australian trial sites. Table 8.2 shows that variation in soil nitrate at planting was a consequence of compost quality and, more specifically maturity, rather than a result of seasonal conditions (Figure 8.1).

Table 8.2. Comparison of compost nitrogen contents and increased soluble soil nitrogen at commencement of trials in Western Australia

Trial	Compost N content			Available soil N (mg/kg) at planting		
	Total N	NH_4 + NO_3	NH_4/NO_3 Ratio	Control	Compost	% Change
N Replacement site (Compost A 30 m^3/ha)						
Crop 1 lettuce	1.3	< 1.0	< 0.1	4.70	5.32	13.2
Crop 2 Carrot	1.3	23	23	3.71	5.01	35.0
Crop 3 lettuce	1.6	89	< 0.1	12.00	13.77	14.8
Crop 4 Carrot	1.2	27	< 0.1	14.92	14.67	-1.7
Crop 5 lettuce	1.4	140	< 0.10	6.55	7.32	11.8
Crop 6 Carrot	1.1	50	> 1.0	8.90	9.78	9.9
Crop 7 lettuce	1.4	110	0.93	6.15	12.35	100.7
System site (Compost 30 m^3/ha)						
S-3 Broccoli	1.5	130	16	3.75	7.00	86.7
S-5 Lettuce	1.6	280	> 280	3.75	13.75	266.7

Note: Soil available nitrogen levels of 12.35 (Crop 7) and 13.75 (S-5) provide a nitrogen concentration of 190 and 265ppm in soil solution, based on 10% volumetric water at field capacity of these coarse sands.

The importance of nitrogen in the soil solution at crop establishment was highlighted in the final Nitrogen replacement trial. Analysis of soil nitrate concentration at planting accounted for 90% of the variation in total lettuce plant weight across the range of nitrogen rates (Figure 1.17) and illustrated the benefit of the additional soluble nitrogen associated with the compost treatments.

This is supported by comparing the analysis of compost nitrogen levels with the levels of plant available nitrogen in soil at planting (Table 8.2). Note that on three occasions, large increases in mineralisation occurred when the compost had adequate levels of inorganic nitrogen (>100 mg/L) in the nitrate form. This relationship between the plant available nitrate nitrogen content of compost and its potential to improve crop yield was identified in Californian compost maturity investigations with vegetables (Buchanan 2002). It was also supported by yield improvements associated with two of the three Western Australian trials where significant mineralisation occurred (Table 8.2).

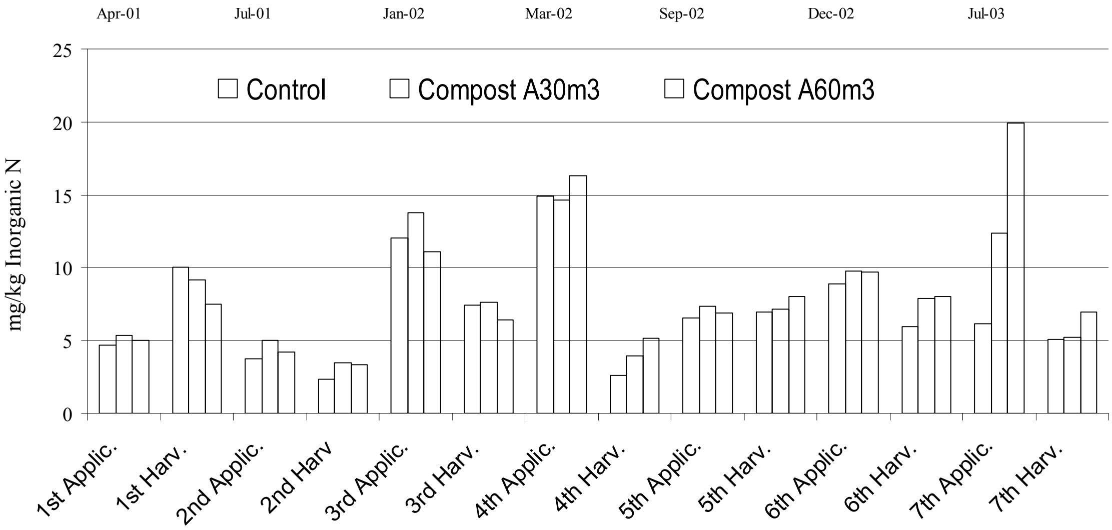

Figure 8.1. Seasonal nitrogen mineralisation at planting and at harvest for the seven trials at the Nitrogen Replacement site from April 2001 to July 2003.

The lack of crop response to compost despite high levels of soil nitrate in the final system trial (S-5) can be explained by the increased frequency of early fertiliser nitrogen adopted for this trial (see discussions page 181). Trial 5 at the Nitrogen Replacement site also demonstrates the importance of compost maturity on mineralisation and nitrate nitrogen. This compost had adequate inorganic nitrogen (140 mg/L) however, it was in the ammonium form indicating that at best, this compost was very immature and did not stimulate soil mineralisation of organic nitrogen.

Soil analysis from the fourth crop at the Victorian Nitrogen replacement site indicated that compost increased total soil nitrogen by 50% but reduced soluble nitrogen by almost 10% (Table 2.14). Although the compost used met most of the specified criteria (Table 2.13), a notable exception was the 0.07 Nitrate to Ammonium nitrogen ration that is below the suggested value of greater than 0.14. This again emphasised the importance of compost quality and its impact on nitrogen mineralisation.

Compost that strongly stimulate Nitrate nitrogen levels in the soil solution are therefore likely to produce the best results in terms of crop performance.

The Western Australian system site demonstrated that in the presence of clay, the nitrogen applied as compost together with some of the fertiliser applied nitrogen was retained (Figure 1.43 and Figure 3.9) and that compost alone reduced nitrogen loss. The percentage of compost nitrogen retained was 148% for compost plus clay and 82% for compost alone (Table 3.38). Despite continued commercial application control plots lost 11% of its soil nitrogen over the 5 crops. Leachate analysis also confirmed that nitrogen leaching, over an 8 month period, was reduced 14% with compost and 26% with the compost plus clay treatment (Table 3.43).

Minor and heavy metal levels were analysed in 12 of the composts used at the Fertiliser replacement and System trial sites in WA (Table 8.3). The only metals of concern were copper and zinc. Eight of the 12 samples would have exceeded the "Biosolids Adjusted Contaminant Concentration" (BACC) for copper and 11 would have exceeded it for zinc.

Table 8.3 Concentration of heavy and minor metals in 12 composts used during the Project

Metal (mg/kg db)	Mean	Min	Max	SD	BACC* Grade C1	Samples exceeding BACC
Arsenic (As)	1.3	0.9	4.0	0.99	20	0
Boron (B)	16	0.1	26.0	7.31		
Cadmium (C)	<1.0	< 1.0	<1.0	0.00	3	0
Chromium (Cr)	6.4	<1.0	12.0	4.01	100	0
Copper (Cu)	92	52.0	190.0	42.53	100	8
Lead (Pb)	7.8	<1.0	16.0	5.62	150	0
Manganese (Mn)	169	69.0	290.0	65.57		
Mercury (Hg)	<1.0	<1.0	<1.0	0.00	1	0
Molybdenum (Mo)	2.7	<1.0	5.8	2.08		
Nickel (Nc)	3.5	0.9	8.5	2.59	60	0
Sodium (Na)(%)	0.21	0.1	0.3	0.03		
Zinc (Zn)	195	80.0	450.0	104.92	200	11

*Contaminant grading, Biosolids Adjusted Contaminant Concentration, “Guidelines for Direct Land Application of Biosolids and Biosolids Products (Department of Health, Perth, WA)”. BACC = Mean + SD.

Despite the perceived high concentration of these two elements soil analysis (Mehlich 3 Extraction) after 7 applications of compost plus additional fertiliser additions of copper and zinc, recorded only a small increase for zinc and a slight decrease for copper in compost treated plots. Increases were recorded for the essential nutrients boron, calcium, magnesium and sulphur. Decreases were recorded for Cadmium and Molybdenum (Table 8.4).

Table 8.4 Soil concentration of selected metals after 7 applications of Compost (N Site)

Metal (mg/kg db)	Control	30 m^3/ha	60 m^3/ha	Grade C1**
Arsenic (As)	n/a			20
Boron (B)	0.10a*	0.34b	0.48c	
Cadmium (C)	0.03a	0.02b	0.02b	1
Calcium	625a	1250b	1750c	
Cobalt	0.052a	0.049a	0.048a	
Chromium (Cr)	n/a			100 - 400
Copper (Cu)	6.4a	5.8b	4.8c	100 - 200
Iron (Fe)	102a	108a	112a	
Potassium (K)	42a	48a	57a	
Lead (Pb)	n/a			150 - 300
Magnesium (Mg)	26a	63b	97c	
Manganese (Mn)	16a	17a	16a	
Mercury (Hg)	n/a			1
Molybdenum (Mo)	0.10a	0.07b	0.05b	
Nickel (Nc)	0.25a	0.15b	0.13b	60
Sodium (Na)	3.0a	5.0b	6.8b	
Sulphur (S)	3.8a	8.0b	7.5c	
Zinc (Zn)	8.6a	10.8b	11.2b	200 - 250

* Values in rows followed by a common letter are not different (P > 0.05)

** Soil Contaminant Ceiling Concentration, "Guidelines for Sewerage Systems" National Resource Management Ministerial Council November 2004, Canberra ACT.

Soil health: Improvements in two important aspects of soil health, namely microbial activity (Figures 6.4 and 6.5) and microbial diversity (Table 6.2 and Figure 6.2), have been measured at the Medina trial sites in WA as part of the doctoral studentship associated with the project. Increases in microbial activity have also been measured at the Victorian System trial site (Table 6.4).

In addition to managing losses of soluble nutrients, maintaining effective diverse microbial populations is also likely to be the key to managing many pests and diseases and achieving significant reductions in the use of pesticides (Hoitink 1999).

SOIL HEALTH

- **Compost increases biological activity and diversity.**
- **Active biological populations are responsible for mineralisation and reducing leaching losses.**
- **Biological activity and diversity will potentially reduce the incidence of pests and diseases.**

Strategies for using compost

Achieving maximum benefit from compost use requires a commitment to incorporating the regular use of compost into vegetable growing programs.

Over time, application rates are likely to reduce and or to be restricted to the most responsive crops. However rates and frequencies will inevitably be governed by the production system, prevailing soil and climate, and the need to maintain soil carbon at adequate levels.

At this stage strategies for using compost in vegetable production should include:

- A commitment to its regular use.
- Apply compost at between 20 and 30 m^3/ha and at higher if soil quality is an issue.
- The use of soil and crop analysis to adjust fertiliser programs and manage compost rate.
- Taking time to work with and build a relationship with the compost supplier.
- Working with compost suppliers that provide product information including information on nitrogen content.
- Working with industry suppliers and technical consultants that are knowledgeable in soil management as well as crop production and that demonstrate a commitment to the conservation and development of soil organic matter; and
- A healthy scepticism for statements that promise with great certainty, immediate positive results in all situations.

COMPOST USE STRATEGIES

- **Regular use;**
- **Use of soil and crop analysis;**
- **Adjust fertiliser programs;**
- **Build relationship with reputable supplier;**
- **Use products with available nitrogen (mainly Nitrate N) greater than 100 mg/L.**

Knowledge of soil quality and fertility and its impacts on vegetable crop performance are in the early stages of development however, with common sense and the application of current knowledge, they offer exciting possibilities for:

- Managing and producing high quality crops.
- Significantly reducing inputs of fertiliser, irrigation and potentially pesticide use; and
- Maintaining and improving soil and water quality.

Using compost is first and foremost a tool for improving soil performance and as we learn more about better managing soil organic matter levels, benefits of reduced pesticide and irrigation will become increasingly significant.

Economic considerations

Economic considerations focus on the use of compost alone, however the economics of using clay as a soil amendment are considered briefly.

Returns from using compost depend on improvements to marketable yield and savings in management cost. Management savings universally include reduced fertiliser requirements and with continued compost use there will be irrigation savings and potentially significant pesticide savings.

FINANCIAL BENEFIT
Compost use will improve returns providing:

- **it is used regularly;**
- **quality is appropriate;**
- **fertiliser rates are reduced and managed.**

There will also be benefits associated with increased harvesting efficiency and improved product quality that contribute to better shelf life and increased nutritional value of fresh vegetables.

Because many of these benefits are likely to be site specific and the result of further developments with 'better management practices', we will restrict our economic analysis of compost use to yield improvements typically achieved and fertiliser savings identified in crops grown with compost for the first time.

Using basic Gross Margin Analysis, the increased yield required to cover the cost of a 25 m^3/ha application of compost to selected vegetable crops grown for the domestic Perth market are provided in Table 8.3.

The basic assumptions used for costing compost are:

- *Applied cost* - $42/ha including:
  - Application cost - $7/$m^3$ and transport cost - $5/$m^3$
- *Fertiliser saving* - $20/$m^3$ based on research results and cost of urea, superphosphate,
  - potassium sulphate, Agricultural lime and Magnesium sulphate.
- *Compost analysis* - (%); N – 1.5; P – 0.8; K – 0.7; Ca – 2.8 and Mg – 0.30.
- *Crop returns* - Local market prices provided by the Perth Market Authority.
- *Irrigation* - Pesticide and harvest savings; Nil.
- *Marketable crop yields* - Based on mid range typically achieved in our trials, they are within the upper mid range of grower expectations.

Table 8.3. Percentage increase in yield necessary to cover the cost of applying 25 m^3/ha of premium grade compost to selected vegetable crops

Crop	Marketable yield	Unit	Market return $/unit		% yield increase to cover cost of compost	
			Low	High	Minimum	Maximum
Lettuce	3,800	Crates/ha	5.00	10.00	1.2	2.9
Broccoli	12,000	kg/ha	0.75	1.00	4.6	6.1
Carrots	71,550	kg/ha	0.50	0.75	0.7	1.2

The estimated percentage increases in marketable yield are within the yield improvements typically achieved in our work and underpin the conviction that the regular use of high quality compost will provide a positive return.

The critical issue is that typical improvements to returns based on fertiliser savings and a 4% to 7% improvement in marketable crop for lettuce and broccoli and 2-3% for carrots typically range from \$200 to \$900/ha and are relatively small, particularly when compared to production costs (Paulin 2004).

With regular compost use, improvements to grower returns will increase and importantly, very significant increases will be achieved from time to time when improved soil performance is able to substantially reduce impacts of management failure and or climatic extremes.

The level of increases will be predicated on growers making appropriate adjustments to fertiliser programs that will increasingly account for their costs of compost application. As indicated from the fertiliser replacement work, two thirds of the compost cost can be covered by reductions in requirements based on the cheapest fertiliser alternatives and given the increasing use of expensive compound fertiliser, these savings have the potential to cover the entire cost of compost.

Irrigation savings have not been considered, largely because of the relative low cost of self supply irrigation that predominates in Western Australia. With irrigation reductions of less than 10% and supply costs in the order of \$0.08 to \$0.12/Kl (Gartrell 1998) savings are in the order of \$240 to \$360/ha/yr. These estimates are based on a typical 30,000 Kl/ha irrigation use around Perth in Western Australia and it should be acknowledged that if the costs of irrigation increase to around \$0.50/Kl then savings would increase \$1,500/ha/yr.

With respect to the use of clay, the cost of application is a major consideration, and while it is not possible to accurately estimate, currently it would be in the order of several thousand dollars per hectare. Least costs application strategies need to be evaluated and although there are sources of material, there is no supply industry in place on which to base costs. From our preliminary findings, savings are at least twice that of compost alone, so that savings would initially be in the order of \$500 to \$700 increasing up to \$3,000/ha/yr if irrigation supply costs rise to \$0.50 Kl.

As irrigation supply costs increase, the use of clay is likely to become an increasingly viable option, at least on much of the Swan Coastal Plain in Western Australia.

Developing the vegetable industry compost market

Issues for consideration include:

- cost and value of benefits;
- compost quality and maturation, issues associated with determining compost quality and the 'fitness for purpose' of a given product;
- building linkages between vegetable production and the community through considerations for managing wastes and a range of other mutual benefits.

Compost cost and value of benefits

Benefits of reduced and more efficient use of fertiliser and irrigation can only be achieved when appropriate changes are made to relevant management practices. With sands and very light soils, maximising these benefits and reducing pesticide use in vegetable production is likely to require greater soil carbon levels than can be achieved under current management systems.

Enabling growers to achieve these benefits and particularly fertiliser savings with minimal disruption to tight and often complex cropping schedules will require the information developed to be packaged effectively and most usefully in electronic formats.

These packages should be developed to also assist growers with improving their overall management practices and should incorporate capacity to cost changes and estimate associated changes to returns.

Electronic packages need the capacity to interpret soil analysis results, adjust fertiliser and irrigation programs to match identified best nutrient management practice and ultimately, to assist with making changes to pesticide use that is compatible with integrated programs for managing disease, pests and weeds.

Growers are under increasing pressure to reduce the potential adversely impacts of their management practices on soil and water resources. Participation in building better overall management programs that encompass soil management will invariably result in clearer recognition of the importance of building and managing soil organic matter levels. In the intensively managed horticultural industries, the importance of using compost to manage soil organic matter will become increasingly obvious and will serve to promote these benefits that are not accounted for within normal costing processes.

Current costs and relatively small benefits that frequently arise make the costs of applying compost a major limitation. While it has greater long term value in terms of improving soil carbon levels (Figure 6.1) and associated soil performance, compost is not competitive with raw manures and other organic products that are currently available.

In Western Australia, raw poultry manure costs less than half the applied cost per cubic metre of compost. Poultry manure also contains over twice the nitrogen content (3.5% compared to < 1.5%) and that nitrogen is much more readily available. While that nitrogen will also leach more readily its greater availability is what is important within conventional management programs and with the unit cost, explains grower reluctance to consider the use of compost.

Serious consideration therefore needs to be given to making the use of compost more economically attractive to growers, at least in the short term so that they have the opportunity to use it and appreciate the greater range of benefits that will accrue over time. This could be achieved by providing rebates on compost use that could be funded from landfill levies. The supply of compost that consistently provides plant available nitrogen at crop establishment will also increase the value of compost to the vegetable industry.

Finally many of the benefits associated with improved soil quality and performance are not realised in any financial sense and therefore at least in the short term cannot be factored into finance based decision processes. This is further reason for considering processes that encourage the use of compost over an extended period of time to enable these benefits to develop and reflect in at least a level of financial saving.

Compost quality and maturation

Compost maturity is the factor that determines compost quality in terms of its best use and it reflects the degree to which the second mesophyllic composting stage (Figure 8.1) has progressed.

There are large volumes of research into compost maturity and a consistent conclusion is that it cannot be defined by a single measurement. Recent work to develop a compost maturity index by a group lead by Dr Marc Buchanan (Cotton 2002) for the Californian Compost Quality Council (CCQC) has considerable promise.

The CCQC compost maturity index involves three tests that include the Carbon: Nitrogen ratio, one test for potential plant toxicity (germination, Ammonium nitrogen level) and one for compost stability (rate of oxygen uptake, carbon dioxide production, Reheat test). Based on critical values from each of the tests, the compost is given a maturity score/rating between 1 (immature) and 5 (highly mature).

This index has been validated using an extensive range of commercial composts in commercial vegetable trials (Buchanan 2002). This work indicated that composts with a rating of 2 to 3 are most likely to improve crop performance through its ability to supply crop available nitrogen. The potential importance of this maturity rating is to provide a quantitative measure of maturity and enable the production of more consistently performing compost.

The suite of analysis conducted for the composts used in this project did not include a test for stability. However nitrogen analysis values that are within the established limits for total inorganic nitrogen (>100 mg/L) and the dominance of Nitrate nitrogen (Nitrate to Ammonium nitrogen ratio >0.14) indicate a compost is likely to stimulate mineralisation, and perform well in vegetable production providing soil organic nitrogen reserves are adequate.

Compost with adequate plant available nitrogen that is predominantly in the Nitrate form is likely to perform well in vegetable production.

Investigation the Californian Compost Maturity Index under Australian conditions and with local composts would provide opportunity to further test our findings with respect to compost nitrogen analysis and to confirm that maturity levels are useful in quantifying the potential for achieving other benefits from compost use.

Composts made with woody wastes as a significant component of the feedstock present additional considerations. Decomposition of woody lignified materials, particularly during the initial composting phase is limited because the bacteria responsible can only act on the exposed surface carbon. Unless time is not a concern, the production of compost from woody feedstock needs to involve screening to remove larger fractions that potentially contain undecomposed carbon.

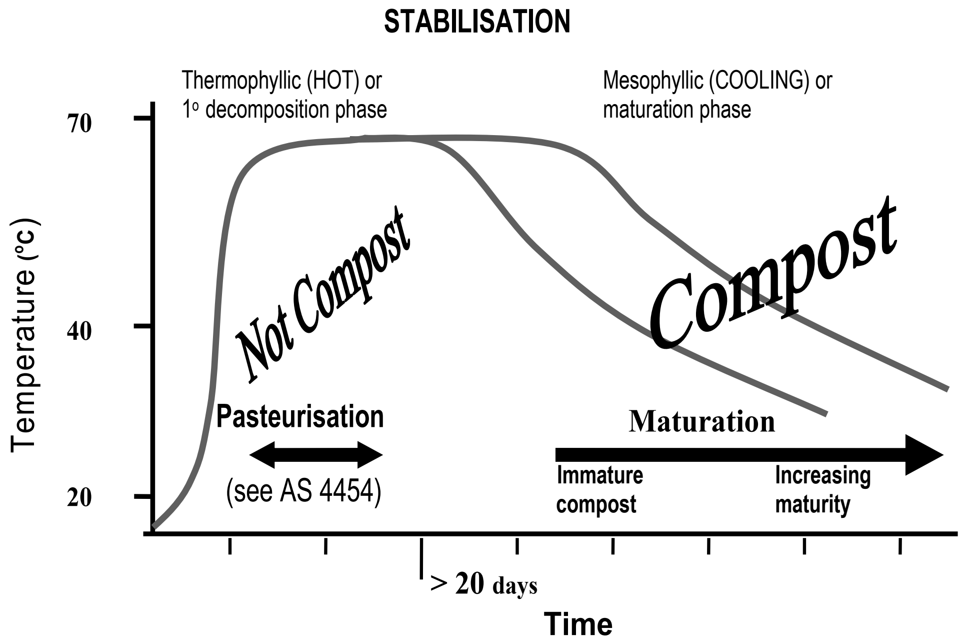

Figure 8.1. Diagrammatic depiction of the vessel composting process.

With conventional windrow composting the normal expectation is to produce compost for use in vegetable production within 10 to 14 weeks. Our work backed up by findings of a recent tour of compost production in California (Paulin 2002) indicate that to achieve this using woody feedstock's, screen sizes in the order of 10 mm are required

Role of standards and regulation

The Australian Standards for Compost, Soil Conditioners and Mulches AS-4454, set out a range of minimum test values for compost and related products. They also define procedures and protocols for their measurement.

The standards also define minimum requirements for protecting community health and the quality of our soil and water resources. This is achieved through reference to the Standards for the application of 'Biosolids' to land and to relevant Public Health Standards provided by the Health Act.

All organic wastes posse significant risks to the community, agriculture and natural resources, and composting together with compliance with the Australian Standard AS 4454 manages these risks (Millar 2002).

Manures, sludges and food waste all contain diseases and pests, often high levels of heavy metals, as well as significant levels of nutrient and particularly nitrogen that have the potential to contaminate ground water.

The present uncontrolled distribution of 'raw' mulched plant material contributes to the spread of diseases, pests and weeds, and is totally unacceptable to commercial agriculture and should be unacceptable to the community. This practice also possesses potential biosecurity concerns, particularly when time delays between a biosecurity incursion and its detection allow its significant spread, as was the recent case in California with Sudden Oak decline.

In Californian compost producers are licensed and as part of license conditions, they are required to demonstrate compliance with minimum standards that cover a similar range of issues to those covered within AS 4454. This approach will provide compost users and particularly growers with much greater assurances that a compost product has at least been adequately pasteurised.

The application of these minimum standards through a process that licenses all organic waste industry participants would address the broad range of crop and human health as well as environmental and biosecurity concerns that are associated with organic wastes. It would also address compost's current lack of competitiveness with raw manures and allow all organic products to compete on the basis of performances, rather than just on cost!

Building linkages between agriculture and the community

The benefits from the soil application of organic wastes to soil and water resources, to agricultural productivity, and to the environment are being increasingly better understood.

This is illustrated by a recent resolution by the Soil Science Society of American advocating global enhancement of soil organic matter. The resolution put up for international adoption, stated:

> "**We resolve that organic matter is a resource that must be restored and increased globally to reduce the net rate of increase in greenhouse gases, to increase plant productivity and improve environmental quality**".
> *Global climate change, food security and environmental quality are interrelated issues of importance to all Nations and our Planet, and these can be favourably and simultaneously addressed by global enhancement of soil organic matter.*

The significance of managing soils and particularly the potential to use composted organic waste is also being addressed by the European Union development of a comprehensive policy to protect soil. EU-25, the Thematic Soil Strategy for 'Organic matter and compost quality in the future', brings together the findings of five interdisciplinary working groups. In summarising their work it emphasises the inherent link between soil quality and the use of composted exogenous organic matter.

This project has clearly identified the linkage between soil carbon and the recycling of organic wastes as compost, providing minimum standards for land application are met.

Recognition of the strategic importance of agricultural land in the planning process resulted in the recent establishment of a Statement of Planning Policy for Productive Agricultural Land (SPP 2.5), in Western Australia. However despite this initiative, the planning process continues to support the paradigm that the needs of agriculture are subservient to the requirements for urban growth. This situation and the failure to address it is common to urban development areas throughout Australia and most of the Western World.

Implementing a planning process that addresses the strategic importance of agriculture is likely to be more readily achieved when all of the potentially linkages with sustainable urban development are considered and are fully appreciated. These linkages relate to:

- Agricultures contribution to zero waste objectives through its potential to beneficially reuse the major organic component of the waste stream.
- Recognition that vegetable production and other irrigated horticultural activities are major potential users of reclaimed water via groundwater recharging. To justify the capital investment for this to occur, permanent agricultural zones or precincts will need to be established.

- Agriculture's reuse of organic waste will reduce the negative impacts of these industries on soil and water quality. This outcome will be of greatest immediate importance if the use of reclaimed / recycled water in horticulture, either through direct supply or groundwater recharging, results in the establishment of precincts for long term intensive horticultural production.
- The production of fresh food with maximum nutritional value and therefore maximum potential to reduce health costs requires transport and storage to be minimised and fresh food production to be retained close to urban centres .
- Contribution to employment, tourism and agri-business opportunity and to the diversity of social and community values associated with rural landscapes in the peri urban environment.

Greater appreciation of these linkages and especially the potential for agriculture to utilise reclaimed water and hence free up water for other uses, has the potential to facilitate changes to the current dominance of urban needs in the planning process.

An added benefit from strategic planning process that better accommodates the needs of agriculture and particularly long term food production will be additional protection for natural ecosystems as well as environmental and social values that are associated with rural landscapes. This will come about through the maintaining viable rural economies that will in turn be underpinned by viable intensive horticultural industries and particularly vegetable production.

Conclusions

Fertiliser savings, moderate to small increases in marketable yield, irrigation savings along with other potential benefits to production efficiency and improved environmental outcomes combine to make compelling arguments for the use of compost to contribute to a more productive vegetable industry.

Consistently achieving increased returns from using compost, at least in the short term, will require adjustments to fertiliser applications. The need to adjust fertiliser programs, to store and spread compost, and the perceived risks associated with the capital outlay ($800 to $1,000/ha)required to apply compost at the commencement of the crop cycle, explains the relatively slow adoption of compost use and emphasises the need for:

- The provision of services that better enable growers to adapt their practices and capitalise on the benefits associated with compost use, including reduction in fertiliser and potentially irrigation.
- The ability to quantify compost maturity and therefore to ensure that its performance is reliably maximised.
- Keeping compost cost as low as possible by ensuring that costs associated with the collection and management of organic wastes are born by the waste producer rather that the user of the composted product.
- Encouraging the production of compost that is appropriate for use in vegetable production and the adoption of independently audited quality management processes by the compost industry; and
- The potential environmental benefits from compost use, such as more efficient use of irrigation and fertiliser, to translate into additional returns. Policy and regulation that reward growers for managing soil and water resources will inevitably favour shifts in management practice that favour the use of compost.

In addition to direct benefits to productivity and grower returns, our work demonstrates the critical importance of a greater:

- Focus on the importance of soil organic matter in the development of more sustainable, lower input, vegetable production systems; and
- Awareness that conserving and building soil organic matter effectively ‘bullet proofs’ soils, making them more resilient and productive and contributing to the development of ‘best production practices that incorporate a significant ‘EMS – Environmental management system’ focus.

This approach will minimise potential negative management impacts on soil and water quality while minimising costs of fertiliser, irrigation and ultimately pesticide costs.

Without incentives, the adoption of these approaches based on the use of compost and adjustments to management, even when fully developed, will be slow because the benefits tend to be long term and accumulative rather than short term and immediate. The development and adoption of ‘soil carbon based’ practices will be encouraged by:

- Information packages (Electronic and written) that assist growers to change management with minimal disruptions. They also need to be constructed to assist with quality assurance and environmental management.
- Market demands for environmental management systems and greater food safety.
- Increasing costs of water.
- Increasing license requirements for the adoption of more efficient irrigation and fertiliser management practices; and
- Planning processes that better recognise the strategic importance of horticulture in reusing organic wastes as well as reclaimed water, and complimenting urban community needs through providing fresh food, employment, agri-tourism / business opportunities, and contributing to the protection of both community and environmental values.

SECTION 9 – RECOMMENDATIONS

Our work indicates that in most situations, the financial benefits to vegetable grower from using compost are positive but usually small. These investigations have identified that:

- Compost needs to be used regularly;
- Available nitrogen analysis, dominated by Nitrate nitrogen needs to be adequate (>100 mg/L);
- Variable compost quality will frequently reduce benefits and can result in reduced returns; and
- In many situations, increased returns will only be achieved if savings associated with reductions in fertiliser use can be realised.

Develop compost use as integral component of vegetable management program:

- **Identify and develop management practices that maximise soil organic matter**
- **Develop management practices to facilitate grower use of compost with minimal disruption to management**
- **Confirm compost analysis values that identifies best maturity for vegetable production (Maturity index - Available nitrogen >100 mg/L and mainly Nitrate N)**

It is also important to appreciate that making these changes is not a simple matter for many growers!

Finally, mutual benefits to the wider community in general that arise from vegetable industry and other horticultural reuse of organics, need to be included. These benefits include:

- Improved productivity and potentially, the quality of fresh food;
- Environmental benefits that will flow from building soil carbon and related contributions to the development of biological activity, soil health and soil fertility;
- Contribution to achieving 'Zero Waste' objective.

Key issues to be addressed

Factors limiting farmer use of compost

The use of compost, particularly in vegetable production is limited by its cost relative to other organic inputs as well as by policy settings that do not reflect a priority for recycling organic materials back to the land and land use planning process that fails to create permeance within productive agricultural areas that would encourage investment in building soil quality.

A contributing factor to the slow pace of progress with increasing compost use by vegetable growers could also be an inadequate understanding of farming enterprises, what motivates farmers to change practice (in this case to adopt compost products) and what are the barriers to changing existing and developing alternate management practices. 'Practice change' research seeks to address this gap in knowledge by understanding the farming context, identifying needs and designing a more effective management systems and better targeted extension strategy. The modest progress made in developing markets to date through field trials, promotional campaigns and marketing studies could reflect that this background research has not been conducted.

Compost quality

Consistency of compost performance is largely determined by composting process management and reflects its level of maturity. Maturity is a function of the second stage of the composting process (Figure 8.1) and is not readily quantified by any single measurement. Some progress in quantifying maturity has been made by the Californian Integrated Waste Management Board who sponsored the development of a Compost Maturity Index by Dr Mark Buchanan and a panel of noted commercial compost producers in the United States. However analysing the nitrogen content of compost, in line with recommendations for levels and nature of available nitrogen, (Table 3.47) provide a strong indication of its suitability for vegetable production and may be particularly useful for organic growers.

Crop production systems development

The use of compost needs to be viewed and developed as part of the vegetable production system and its widespread use will be more likely when overall system improvement can be achieved. Growing emphasis on developing environmental management systems (EMS) will be facilitated by including the use of composts. Along with a strong focus on soil performance, this will allow the delivery of environmental and socially beneficial changes to management along with the maintenance of critically important productivity and financial security.

Investigating factors and mechanisms that contribute to soil biology and its management under commercial production also need to be included if we are to produce compost that performs reliably and that consistently:

- Stimulates mineralisation and the supply of nitrogen and other nutrients.
- Manages pests, diseases and possibly weeds.

Opportunity to share and discuss current knowledge and experience with building soil carbon based production needs to be facilitated. The process should include an annual two day working conference that focus on developing sustainable soil based production systems for vegetables and other key horticultural industries. They could be held on a rotational basis around Australia at Universities or other similar low cost venues.

Researchers and practitioners involved in soil health, fertility and management that may not have involvement with the use of compost or soil organic matter investigations such as crop rotation, integrated pest management and permanent bed production for vegetables, and inter row sward management/cover cropping in perennial crops, need to be included.

A National workshop for researchers has been held by Compost Australia and needs support for it to become an annual national event.

Information packaging and marketing tool

Generic tools need to be developed that assist growers and consultants with making changes that maximise potential benefits from compost use, such as adjustment to fertiliser programs and other management practices, and that contribute to developing overall environmental management systems. This project has developed information required to develop these tools, however this information needs to be incorporated into user friendly computer based packages.

Short term investigations (< 3 yr)

Investigate factors that limit farmer use of compost

Maximising the benefits of compost use in vegetable production will potentially require changes to production systems and consequently unique adjustments to be made by individual growers. An investigation is needed into the most effective means of facilitating this change. To enable the best extension and research programs to be developed (to facilitate change), social researchers and extension practitioners should be engaged to investigate the needs of farmers and identify the barriers and limits to management change. The aim of this project would be to develop a 'compost adoption strategy' to address the differing needs and drivers for growers in various regions and situations that include key messages and effective delivery mechanisms.

Potentially this process could be developed nationally with the aim of facilitating the development of improved production systems that embrace the 'EMS - Environmental Management System' concept for a wide range of horticultural and agricultural industries. By focussing on managing soils for greater productivity, the role of compost would be dependant on the situation and its associated economic considerations.

In subsequent years a program for implementing the compost adoption strategy should be rolled out, see Long term Production system Development.

Quality/maturity studies

To build on current knowledge and utilising the Californian Compost Maturity Index, undertake:

- Laboratory studies to identify factors in compost production (feedstock/C:N ratio, logged temperature, moisture and turning frequency) and compost analyte values that contribute to crop improvement. This will include refining knowledge on key factors that influence compost performance and determining methodologies.
- Coordinated National program to evaluate the findings using commercial composts applied to vegetable as well as other horticultural crops.

Management tools

Directions for refining and further developing management tools and information packages will result from identifying factors that limit grower use of compost and associated development of improved management systems. In the immediate term it is important to identify and make best use of information that is currently available.

Long term investigations (> 3 yr)

Production system development

The identification of factors that limit compost use in agriculture will provide much of the detail for the development of more productive, as well as, environmentally and socially responsive farming systems. Broadly, achieving significant compost utilisation within vegetable production will be based on grower acceptance of:

- Its benefits;
- How it can be used to address issues and how to maximise its benefits; and
- Its financial benefit.

The focus needs to be on working with growers to identify aspects of their farm and its management that limit crop performance and to provide support that enables solutions to be developed, evaluated and implemented.

A national project could be developed from the proposed needs analysis and would become a key focus for the proposed National Research and Development workshops. The project needs to:

- Have strong grower ownership, a function of the process.
- Work with individual or groups of growers at the 'whole farm' development level.
- Work through grower support groups and consultants.
- Provide support groups of experts – agronomists, soil management as well as pest and disease specialists, etc. that will assist grower decision making.
- Measure and evaluate outcomes of process including the evaluation of options; and
- Test and further develop packaged information and programs.

From the start, the project will also engage with and assist compost producers to better understand grower needs and assist them in the development of appropriate products to best meet those needs.

Rather than assisting with the DIRECT MARKETING OF COMPOST, the focus of this project will be to develop better vegetable production systems based on improving soil performance that will in most situations, result in an increased use of compost.

Integrating the promotion of the potential social and environmental benefits of agricultural compost use, such as community waste management and resource protection, will contribute to developing more appropriate policy and planning processes that will inturn underpin the development of a significant compost market within vegetable production.

Biological initiatives

There are three elements of University based work at PhD or masters level that could potentially be funded in partnership with existing university grant systems.

They would specifically develop the science relating to soil biological attributes that contribute to the production of compost and that:

- Maximise soil carbon accumulation and building related soil properties that will make them productive under vegetable production – 'Bullet proofing these soils';
- Promote effective nitrogen/nutrient cycling; and
- Promote disease and pest suppression.

SECTION 10 – ATTACHMENTS

In addition to an extensive range of power point presentations and papers presented to a wide range of stakeholders and papers presented at state, national and international conferences (see References), a number of articles fact sheets have been produced and are attached.

Vegetable sheet 1 – What is compost

Vegetable sheet 2 – Why use compost

Vegetable sheet 3 – Getting started

Vegetable sheet 4 – Selecting a supplier

Vegetable sheet 5 – Using compost

A number of A10 laminated posters were produced and outlines are attached:

Horticultural compost development program

Why use compost

Producing compost

Compost production

Compost quality

Compost use in vegetable production

Soil biology and agriculture

Soil quality and organic matter

Sustainable community development and Carbon Based Agriculture

Compost production and use in horticulture

Compost production for agricultural use – issues for the developing Recycled Organics Industry – Discussion paper

Department of
Primary Industries

Compost for Vegetable Growers

Fact Sheet 1: What is Compost?

Compost is partially decomposed organic matter produced by naturally occurring microorganisms. Compost is a dark, crumbly mixture that can help improve the chemical, physical and biological aspects of soil. Compost will often have an earthy smell and its odour should not be unpleasant.

Quality compost products can be used to:

- improve and maintain soil quality;
- reduce use of water, fertiliser and pesticides;
- increase productivity, and
- reduce nutrient run-off and soil erosion.

Sheets in this series

What is compost? 1
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How is compost made?

Many different organic materials can be safely composted, including animal manures, garden organics (eg grass, tree prunings etc), food, wood, shellfish & other fish by-products, wool & hair and biosolids. Many of these ingredients can be composted on their own, but the best result often occurs when a number of materials are blended together.

Typically organic materials must be shredded or pre-processed and mixed in a balanced and consistent 'recipe' to ensure optimal conditions for biodegradation to produce high quality and uniform compost. Naturally occurring microorganisms then begin the process of rapid break-down of the organic materials by using the available food (principally carbon and nitrogen), water and oxygen to grow and multiply. The microorganisms generate heat as they break-down the organic matter. This heat (usually in excess of 55 °C) is very important in ensuring that weed seeds and pathogens are eliminated.

This is the first fact sheet in a series for vegetable growers. These sheets will provide you with information about composting, compost products and how to best use them to suit your needs.

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For quality control purposes, composting conditions are monitored regularly, usually by recording moisture content and the internal temperature at several locations within a heap. Heaps are turned frequently (e.g. weekly) for aeration and to mix the outside into the centre (see picture).

PTO-driven compost turner

The entire process is usually complete within 8 to 24 weeks, at which point the compost cools down, and the rate of breakdown slows. The compost is then screened to remove rocks and contaminants and to produce a product with the desired particle size grading (ie coarse or fine grade). This is the point at which composts are most versatile, and can be used for many plant growth and soil conditioning purposes.

Compost quality

Quality composts are safe to use, meeting both industry and government standards and are also 'fit for purpose'.

It is important to first identify why you want to use compost and what you want to achieve. When you have done this, talk to a supplier of quality compost that can help you select the right product for your requirements. The highest form of guarantee for compost is certification to the Australian Standard for Composts, Soil Conditioners and Mulches (AS 4454-1999).

These standards ensure that compost will be safe to use but do not necessarily determine which use they are best suited for.

Further information is available from:

Primary Industries Research Victoria (PIRVic)
Knoxfield Centre, Private Bag 15, Ferntree Gully Delivery Centre, Victoria 3156.
Phone: 03 9210 9222
www.dpi.vic.gov.au

EcoRecycle Victoria
Level 2, 478 Albert St. East
Melbourne Victoria 3002
Phone: 03 9639 3322
www.ecorecycle.vic.gov.au

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Department of
Primary Industries

Compost for Vegetable Growers

Fact Sheet 2: Why Use Compost?

Australian soils generally have low natural fertility, low organic matter levels and are fragile to intensive agricultural practices.

Farming practices have contributed to soil compaction and erosion, which eventually lead to lower soil productivity. These problems are exacerbated when soils are depleted in organic matter. Less productive soils require higher inputs of fertilisers, pesticides and water - at a cost to the grower and the environment.

Compost trials in Victoria and Western Australia showed improved soil organic matter levels and other aspects of soil quality including cation exchange capacity, moisture holding capacity, bulk density, pH and reduced erosion. Marketable yields for a wide range of crops were improved, especially after repeat application of good quality compost.

Compost is not a 'silver bullet' solution, but it can be an important tool for improving soil quality and crop performance.

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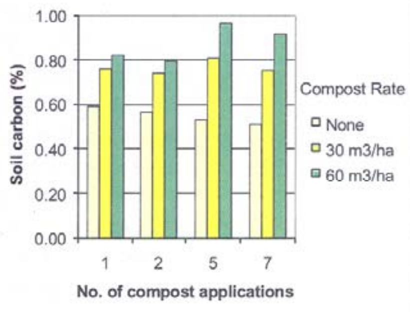
What makes compost so valuable?

Compost is a versatile material that can improve the physical, chemical and biological fertility of soil.

It contains a range of nutrients that contribute to crop growth, however with regular use its greatest value is its contribution to soil carbon (organic matter) levels and biological activity. This results in improved soil quality that in turn allows reduced use of fertiliser, irrigation and potentially, pesticides rates .

Compost contains and contributes to the development of soil humus, which is an advanced state in the decomposition of organic matter. Humus is responsible for many of the benefits usually attributed to soil organic matter and compost.



Regular compost application on sandy soils maintained soil organic carbon levels at a higher level compared to unamended soil. Continual cropping on soil without additions of compost reduced organic carbon levels over time. Source: R. Paulin, P. O'Malley, Dept. Agric. WA.

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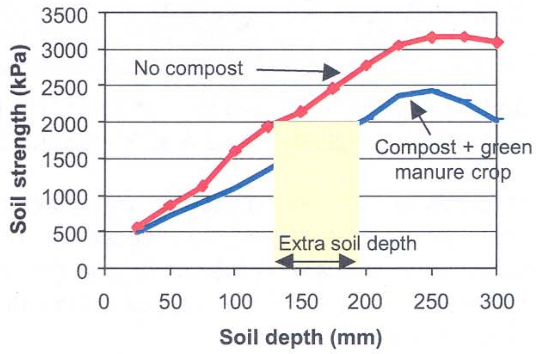
Quality composts can:

Improve Soil Structure

Addition of organic matter reduces soil bulk density by promoting the formation of soil aggregates ('clods') which improve the fiability of the soil.



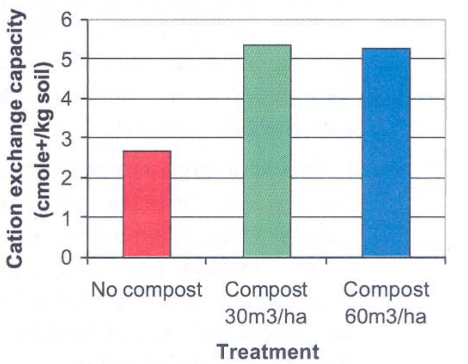
Application of compost at 45 m³/ha together with a green manure crop reduced soil strength and increased the effective depth of a clay loam soil by 60 mm. Root growth at field capacity is severely restricted above 2000 kPa. Source: K. Wilkinson, DPI, Victoria.

Heavy soils become more 'open' or porous and their workability, aeration, drainage and potential moisture availability improves. Composts used on lighter soils improve water holding capacity as well as aeration and drainage.

Improve nutrient management

Compost contains a range of nutrients and trace elements required for most crops.

Many of these nutrients are not immediately available to a crop because they are bound up in organic matter. Nutrients become available as a result of the ongoing decomposition of soil organic matter. Useful quantities of nutrients such as nitrogen are supplied after soil organic matter levels build up following repeat applications of compost. Organic matter in the soil contributes to cation exchange capacity that better holds on to nutrients, keeping these in the root zone where plants can use them. This means reduced losses of nutrients, lower demand for fertilisers, and less potential pollution of groundwater and waterways from nutrient run-off.



Three repeat applications of compost improved the cation exchange capacity (CEC) of a sandy soil. The CEC is a measure of a soil's capacity to hold onto plant available nutrients. Source: R. Paulin, P. O'Malley, Dept Agric. WA.

Quality composts can:

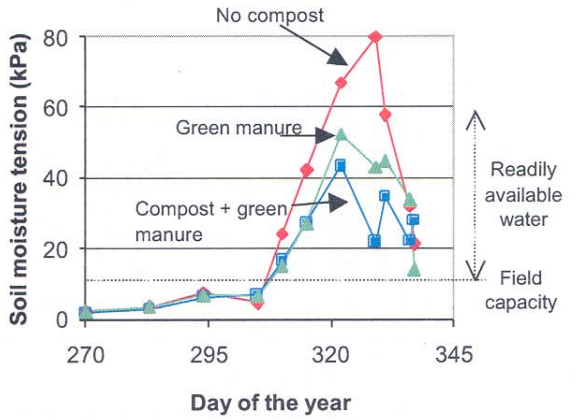
Increase soil moisture

Soil aggregates create a vast network of pores that range in size from fine capillaries to relatively large voids. These capillaries together with humic substances greatly increase soil moisture holding capacity.

These effects can be translated into cost savings from more efficient use of irrigation water. Increases in marketable yields have also been observed as a result of increased plant available water. Increased soil moisture storage lessens the risk of moisture stress and its associated impacts on crop quality.

Improve yields

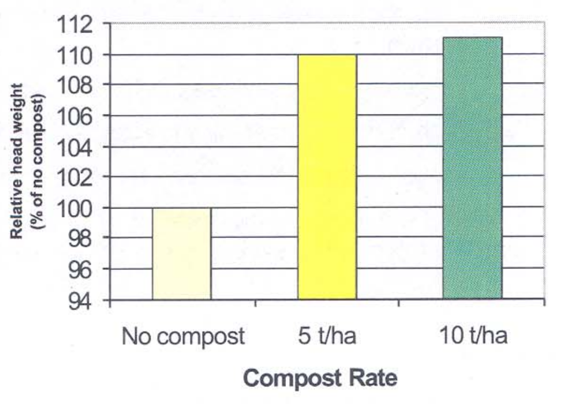
Trials on a range of vegetable crops have found that regular applications of good quality compost can progressively improve crop yields even when less water and fertilizers are used. Best results are most likely to occur on poorly structured soils and with composts containing high levels of available nutrients. In many cases, crops mature faster and more evenly with compost application. Yield and quality improvements are likely to be seen gradually over a number of crops as compost applications progressively improve the soil.



Application of compost at 45m^3/ha together with a green manure crop increased the readily available water (RAW) content of a clay loam soil. RAW is the amount of water in soil that is easily obtainable by plants. Source: K. Wilkinson, DPI, Vic.

Reduce erosion & compaction

Improved soil aggregation increases the soil's resistance to compaction and erosion. Wind erosion, for instance, is a major problem in the establishment of crops in sandy soils.



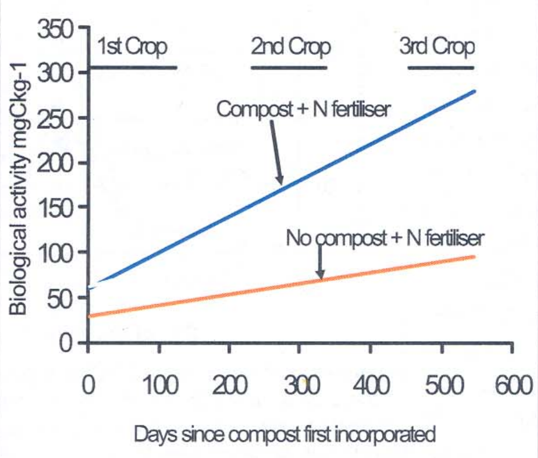
Incorporation of a compost at 5 or 10 t/ha in a red-brown earth soil resulted in about a 10% increase in the head weight of lettuce. Source: K. Wilkinson, DPI, Vic.

Quality composts can:

Support beneficial soil organisms

Soils with high organic matter content usually support a vast number of organisms ranging from relatively large worms and arthropods to nematodes, fungi, protozoa and bacteria. These organisms play important roles in nutrient cycling and soil aggregation.

Biologically active soils are less likely to support disease-causing organisms. Compost has been shown to contain certain micro-organisms that can suppress or kill disease causing organisms such as root rots and nematodes.



Biological activity increases with application of compost at 60m3/ha on sandy soil. Source: R. Paulin, P. O'Malley, Dept. Agric. WA.

Stop Press

Regular use of quality compost in WA and Victoria has shown the following benefits:

- Yield increases of up to 15% for lettuce and broccoli and 1-2% for carrots
- Irrigation water savings of 10% in summer on sandy soils
- Significant fertiliser savings, especially for K and P, and less for N
- Faster maturation of crop and more even crop quality

Taking the cost of compost application into account these benefits were calculated to save a carrot grower about $270/ha!

Further information is available from:

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Compost for Vegetable Growers

Fact Sheet 3: Getting Started

To get the best out of compost, it needs to be used regularly as an integrated part of crop and soil management. Therefore, you need to be clear about what you want the compost to achieve and talk to suppliers about products and methods of using them that will most cost effectively meet your needs.

Use the table below to match your required outcome with the suggested product type (in general terms) and method of application. Detailed advice on product specifications should be supplied by the compost producer.

Desired outcome	Suggested approach
Better soil structure	Regular use of fine grade, mature compost of high organic matter content; Incorporate in soil at planting.
Better soil moisture management	Regular use of fine grade, mature compost; To prevent surface evaporation, mulch soil with compost. Incorporate compost to improve soil water holding capacity.
Reduced erosion	To reduce wind erosion, apply compost on soil surface, and if incorporating, only cultivate into the top few centimeters.
Improved crop establishment and growth	Regular use of fine grade, mature compost; incorporate into soil at planting - if sand-blasting is a problem, apply compost on soil surface then incorporate into soil after harvest.
Better nutrient management	Regular use of fine grade, mature, high nutrient compost (e.g. manure-based composts or compost/fertiliser blends); apply by banding and incorporate at planting.
Control plant pathogens in soil	Regular use of fine grade, mature compost; incorporate into soil at planting.

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This exercise will go a long way in assisting your compost supplier match both your production goals and target benefits with the best product to achieve them. Some suppliers will provide products at discounted rates to encourage commercial growers to try compost. For further information, contact EcoRecycle Victoria on 9639 3322.

Further information is available from:

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Compost for Vegetable Growers

Fact Sheet 4: Choosing a Supplier

The right supplier will help you select the product that matches your broader production goals and specific performance requirements. The supplier must also meet your quality assurance requirements. The best suppliers will also work with you to develop products to match your particular specifications.

Quality assurance

The benchmark for compost quality in Australia is compliance with the Australian Standard for Composts, Soil Conditioners and Mulches (AS 4454). Suppliers of product to organic growers must also be organically certified.

- The highest form of guarantee is certification to AS 4454. Compost producers offering this level of guarantee undergo a rigorous review by an independent third party certifying body. Quality control and on-going compliance are key components of the certification system.

- Many compost producers are not certified to AS 4454, but provide their own guarantee that their product meets the Standard. You can still evaluate these suppliers and their products by asking a few simple questions. The checklist overleaf can help (see page 2).

- Compliance with AS 4454 will not necessarily meet requirements for many applications. The compost supplier must understand your needs and address your questions adequately. In particular, they need to provide you with a regular supply of consistent product and may be able to supply testimonials for specific uses.


Compost heaps tagged for traceability purposes

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Using compost 5

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Recognising certified quality compost

An AS 4454 certified product has:

- The Standards Mark ('five-ticks' logo) clearly visible ☐
- The Standards Australia Manufacturer's Licence Number visible ☐
- A specification sheet supplied with it ☐

Non-certified quality compost

Use this checklist to evaluate non-certified products and their suppliers:

- Producer guarantees the product meets the Australian Standard or other recognised standard (e.g. Organics standard) ☐
- A specification sheet is supplied with the product ☐
- Producer shows traceability from raw material to final product ☐
- Producer shows production records (e.g. temperature monitoring) ☐
- Producer regularly tests products to the Australian Standard or other recognised standard (e.g. Organics standard) ☐

Final selection criteria

Suppliers of both certified and non-certified products should be able to:

- Offer a consistent and regular supply of quality compost ☐
- Show you documented evidence of a quality control system ☐
- Answer any questions you have about the products they offer ☐
- Tell you what a product is made from and how it is made ☐
- Understand your needs and manufacture a product to suit ☐
- Rectify and improve their products based on their performance ☐
- Provide contact details of satisfied customers ☐

Whether you are interested in trying compost for the first time or require a regular supply, these checklists will give you the confidence to choose the right supplier to work with.

Composted products often need to be developed and refined with some degree of 'trial and error', so it is important to establish a relationship with a reputable supplier that you feel you can work with for mutual benefit.

Further information is available from:

Primary Industries Research Victoria (PIRVic) Knoxfield Centre, Private Bag 15, Ferntree Gully Delivery Centre, Victoria 3156.
Phone: 03 9210 9222
www.dpi.vic.gov.au

EcoRecycle Victoria
Level 2, 478 Albert St. East
Melbourne Victoria 3002
Phone: 03 9639 3322
www.ecorecycle.vic.gov.au

Department of Agriculture, Western Australia,
Locked Bag 4, Bentley Delivery Centre,
Western Australia 6983,
Phone: 08 9368 3333
www.agric.wa.gov.au

ISBN 1 74146 277 0; Set ISBN 1 74146 276 2

Department of
Primary Industries

Compost for Vegetable Growers

Fact Sheet 5: Using Compost

The type of product you choose and the method of application depends on your production goals and your specific performance requirements (see Sheet 3, Getting started). Your compost supplier should match your needs with a particular product, giving specific advice on method and rates of application. This fact sheet provides you with some general guidelines about quality criteria for compost and how it can be used in vegetable production.

Compost quality

The Australian Standard (AS 4454) provides a framework for the production of quality compost and for quality assurance (see Sheet 4, Selecting the supplier). However, an Australian Standard compost also needs to be 'fit for purpose'. In general composts should be:

- Compliant with AS 4454 specifications
- Stable and of appropriate maturity (see below)
- Finely screened to remove chunky particles, rocks and plastic.
- Moist, but not wet or dusty
- Neutral or pleasant smelling

Stability is the level of biological activity in a moist and aerated compost pile. In contrast to unstable composts, they are unlikely to compete with crops for available nitrogen or cause oxygen deficiency in soil. Compost maturity is related to stability but reflects the level of further composting that has occurred. There are a few tell-tale signs to look for when predicting the stability and maturity of composts:

- Unstable composts can be odorous and very hot
- Stable composts take 6-12 weeks to make. A further 4 weeks or so is usually needed to reach an appropriate level of maturity for most applications in vegetable production (through a process called 'maturation')
- Check the specification sheet that comes with your compost - the carbon to nitrogen ratio (C/N) should be under 20:1 and toxicity (a plant growth screening test) should be greater than 60%

Avoid using unstable or immature composts in vegetable production, and if they are used, apply them to soil at least 4 weeks prior to planting or sowing. Additional fertiliser nitrogen may also have to be applied with unstable composts to prevent nitrogen deficiency in crops.

Sheets in this series

What is compost? 1
Why use compost? 2
Getting started 3
Choosing a supplier 4
Using compost 5

Application methods

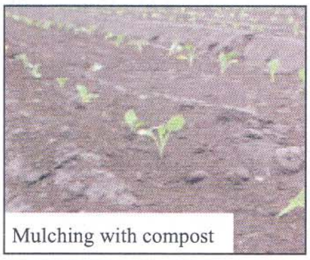
Apply compost just before planting and leave it on the soil surface for mulching or incorporate it in the soil. In general:

- The maximum rate of application should not exceed 60m³/ha/year, applied either in a single application or split-up over the year. Higher rates might initially be needed for degraded soil, but in most cases continued application above this rate would not be economical
- If the compost is to be incorporated, incorporate it to the top 10 cm or so of the soil
- When mulching, apply 2-5 mm thick on the surface of the bed.

Trenching compost

Banding compost

Broadcasting of compost is the fastest way to improve soil conditions across a paddock. Restricting application to planting beds, placement in trenches or banding can be used to reduce total application requirements and therefore costs. These approaches are recommended where compost is applied to supply nutrients to a crop and for improving crop establishment.



Mulching with compost

Mulching reduces evaporation and saves irrigation water. It will also help control some weeds. Mulching is particularly useful on sandy soils that are prone to wind erosion which causes sand-blasting of young crops.

Plan to succeed

Getting the most out of compost is achieved by carefully selecting the right product and monitoring soil conditions and crop performance after compost application. Adjustments should be made to fertilizer rates according to the nutrient content of the compost. As a rule of thumb, stable composts will contribute no more than 15% of its total N content to the crop in the first year. In the second and third years an additional 10-15% (in total) becomes available. These figures are often difficult to estimate because they are site and compost specific. While these contributions are small, N fertiliser rates can be gradually reduced after soil organic matter levels increase from regular application of compost. In contrast, P, K, Mg, Ca and trace elements are available and fertiliser applications of these nutrients can be more quickly reduced.

Further information is available from:

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HORTICULTURAL COMPOST DEVELOPMENT PROGRAM

A PARTNERSHIP BETWEEN HORTICULTURE, COMPOST PRODUCERS, WASTE MANAGEMENT, UNIVERSITIES & THE COMMUNITY

Program Intention

- Improve competitiveness & sustainability of horticulture through the development of soil carbon based production systems
- Maximise horticulture's potential as a market for composted agricultural & urban waste

Coordination

- Stakeholder & specific working groups that assist with communication & enable widest possible input & direction to the work
- Funding from many sources - government, horticultural industries, community (through landfill levies), Horticulture Australia Ltd & others

POTENTIAL BENEFITS

Reasons for this work

- Increase crop yields & quality
- Increased food safety
- increased markets
- Improve soil organic matter & soil health
- Assist organic production

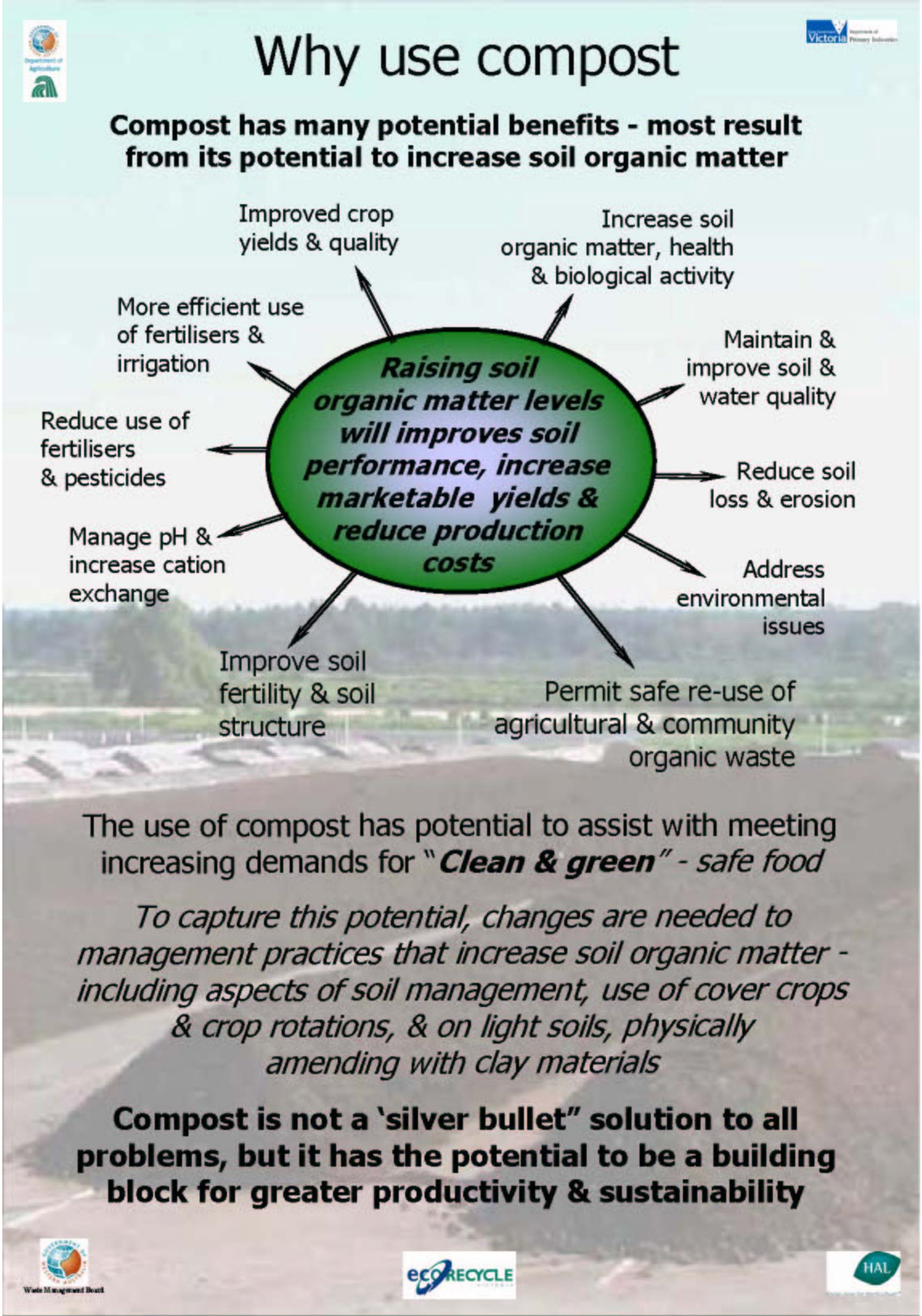
CONCERNS

Limits to adoption

- Cost
- Quality & consistency
- Disease & heavy metal contamination
- How to use
- What it is made from

FOCUS OF COMPOST WORK

- Develop strategies for using compost in a range of crops
- Quantify benefits - production improvement, reduced fertiliser, irrigation & pesticide use
- Identify & promote compost quality requirements;
- Promote benefits of compost to horticulture & the waste industry
- Quantify environmental benefit
- Encourage & promote stakeholder communication


Why use compost
Compost has many potential benefits - most result from its potential to increase soil organic matter
Improved crop yields & quality
Increase soil organic matter, health & biological activity
More efficient use of fertilisers & irrigation
Maintain & improve soil & water quality
Reduce use of fertilisers & pesticides
Raising soil organic matter levels will improves soil performance, increase marketable yields & reduce production costs
Reduce soil loss & erosion
Manage pH & increase cation exchange
Address environmental issues
Improve soil fertility & soil structure
Permit safe re-use of agricultural & community organic waste
The use of compost has potential to assist with meeting increasing demands for "Clean & green" - safe food
To capture this potential, changes are needed to management practices that increase soil organic matter - including aspects of soil management, use of cover crops & crop rotations, & on light soils, physically amending with clay materials
Compost is not a 'silver bullet" solution to all problems, but it has the potential to be a building block for greater productivity & sustainability
Waste Management Board
ecoRECYCLE
HAL

Producing compost

Locating the facility

- Consider potential markets - requirements & returns
- Identify feedstock availability - quantity, quality & supply
- Identify environmental & planning requirements associated with potential site - buffers, nutrient loss management & monitoring requirements
- Undertake extensive community consultation

Select process & equipment requirements

Open windrow - lowest cost, consider windrow size, area requirements including equipment turning; buffers and odour consideration can limit feedstock selection

Static pile & In-vessel - Capital intensive however minimises buffer requirements as well as approval delays & permits widest feedstock selection requirements. Maximises process control & therefore reduces processing time.

Open windrow

Static pile

In-vessel

Allow adequate time 12 - 18 months

Consult
↓
Develop an implementable business plan
↓
Obtain planning approvals

Community consultation

Finalising the proposal

Implement the plan

Compost Production

Composting is the managed aerobic decomposition of organic materials that results in a product that can be beneficially used in agricultural production

Feedstocks/ingredients

- Diversity - increased range adds to potential biological diversity &
- Source separated feedstocks maximise potential compost quality

Top left corner clockwise - crop waste, straw, green waste, wood waste, manure

Range of compost feedstocks

Blend & mixing feedstocks

- Aim for Carbon:Nitrogen ratio of 25:1 to 35:1
- Uniformly mix feedstocks
- Coarse woody materials aids porosity

Curbside green waste

Managing the process

Focus on the pile core & maintain

- moisture content (45% - 60%)
- temperature ($<70^{o}C$, ideally $<65^{o}C$)
- adequate oxygen (O_2) levels (> 12%)

Process control

Composting is a living process, management includes:

- Routine data collection
- Regularly monitoring of temperature, moisture, O_2, & feedstock quality
- Process management based on feedstock, conditions & management, *not just time !*
- Use of quality management principles – allows traceability
- Use combination of process time & process monitoring to set maturity, level see Figure
- Fine screen (10mm mesh or less) to remove potentially none-decomposed woody material

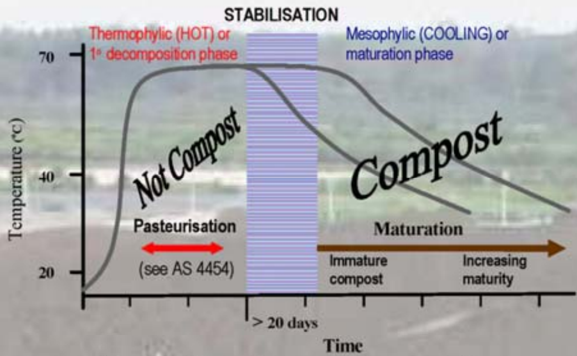


Figure: Two stages of composting
Simplified diagram based on static pile or in-vessel composting

Monitoring O_2 & temperature in the pile

Maturity is major factor in compost quality

MURDOCH UNIVERSITY

Centre for Organic Waste Management

WA Compost Industry Association

Waste Management Board

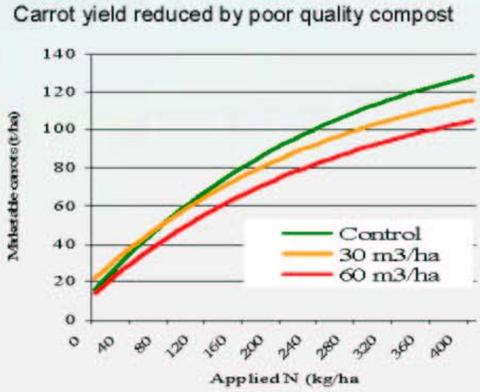
Compost Quality

Quality relates to suitability for an intended use & performance consistency

Process management can have greater affect on quality than composting method & feedstocks used. Feedstocks influence nutrient levels & processing time *e.g. woody materials compost more slowly*

Compost quality -relates to use

- Level of maturity
- Consistency – process control
- Nutrient content
- Freedom from pests, pathogens & weeds
- Contaminant levels



Types of product

- Pasteurised product - subjected to minimum temperature & moisture requirements to control pests, diseases & weed seeds - defined in compost standards AS 4454. These products are NOT compost
- Stabilised product – safe to store, Initial decomposition *(hot - thermophylic)* composting phase completed – Result is IMMATURE compost with restricted safe use!

Further processing increases maturity & therefore its quality aspects of compost performance

Performance & consistency

- More dependent on process management & composting conditions than processing time
- Process management requires regular monitoring & recording

Other aspects

- Woody, green waste based compost needs to be fine screened (10mm or less)
- Including around 25% of woody material aids pile structure & aeration, promotes fungal activity & can increase stable organic matter (humic compounds) in the soil

Indicators of compost quality are:

- Product Specification Sheets that provide data *(from certified laboratory)* on quality ***(C:N ratio, Organic matter level, NO_3/NH_4 ratio, toxicity)***, nutrient content & contaminant levels
- Quality Management Programs that verify process control & adherence to compost Standards AS 4454

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Compost Use - Vegetables

The use of compost increases returns increase by improving marketable yields and reducing fertiliser requirements. Regular use increases soil quality further increasing savings

Fertiliser savings based on lowest cost fertilisers cover 50% to 65% of compost cost

Improvements achieved with wide range of crops

Other benefits fewer harvests (cauliflower) & reduced quality problems (forking in carrots).

Compost research program - lettuce trial

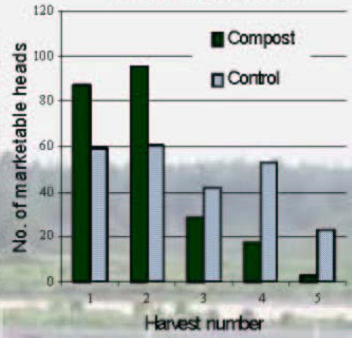
Commercial application

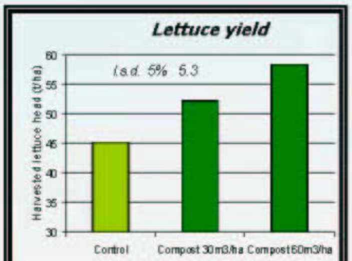
Compost application rates & quality

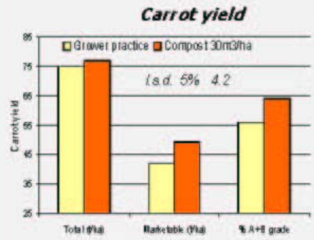
Rates	15 to 30 m3/ha
C:N ratio	< 20
NDI*	> 0.5*
NO3/NH4 ratio	> 0.14
Toxicity	> 60

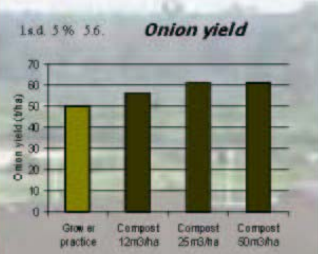
Refer to Australian Compost standards AS 4454
* NDI Nitrogen draw down * optimal > 0.8

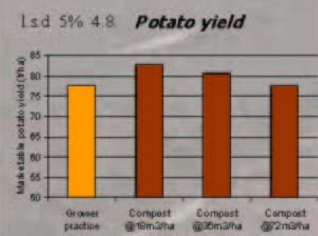
Compost reduces number of cauliflower harvests











← Banding

Broadcasting →

Recommendations

Getting best results requires:

- Appropriate quality
- Regular use
- Adjustments to fertiliser application
- Regular crop nutrient monitoring

Other benefits

Regular compost use:

- Increases organic matter
- Increases soil nitrogen reserves
- Maintains neutral soil pH
- Increases cation exchange capacity
- Reduces erosion

Work is needed to develop management practices that will maximise benefits of compost use vegetable production

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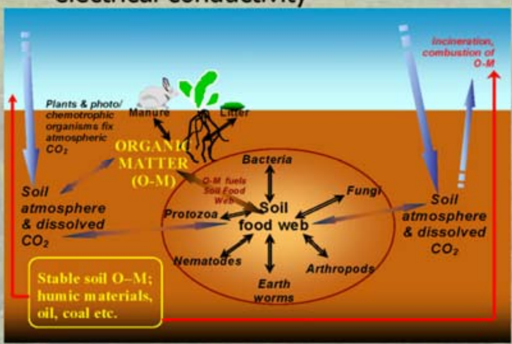
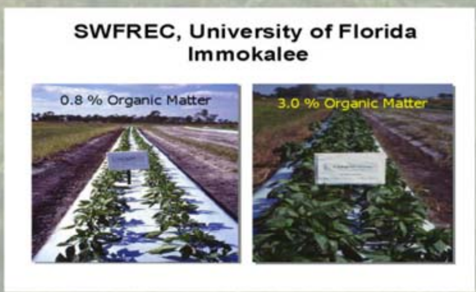
Soil quality & organic matter

Components of soil quality

- Physical - ratio of sand, silt & clay components - impacts micro aggregation, water holding & infiltration, & nutrient supply (cation exchange)
- Organic - Organic matter – soil health and fertility, nutrient cycling (especially N, S & P) & maintaining soil biology
- Chemical - nutrient content, pH, & electrical conductivity



Soil organic matter cycling



Capsicum grown on Florida sands with two levels of organic matter

Organic matter

- Fuels biological activity - *soil food web*
- Aerobic microbes, bacteria, fungi protozoa as well as nematodes play central role in soil food web
- Larger organisms such as earthworms & arthropods shred organic matter & maintain soil aeration

Fungi & bacterial decomposition products & clays, bind & cement soil particles into aggregates that are the basis of soil structure & health

Soil aggregates provide a complex array of pore sizes & networks that

- increase plant available water
- provide "housing"/habitats for microbes & larger organisms

Organic matter levels for optimal biological performance varies with soil type & climate

- The impact of climate on soil organic matter is less significant in horticulture because of irrigation
- For optimum results, it is likely that soil carbon levels need to reach 2.0% in coarse sands & 3.0-3.5% in lighter loams

A complex/diverse array of soil microbes have the potential to play a significant role in pest & diseases management

Organic matter fuels the soil food web
- it needs to be continually replaced

Compost is "safe to use" organic matter. Apart from mycorrhizal fungi, nematodes & higher organisms it also introduces additional beneficial microbe

The compost process represents accelerated natural decomposition that supplies a complex range of compounds [sugars to humic acids] to the soil food web that contributes to soil performance/quality

Clay plays an important role in soil aggregate development & contributes to soil health & organic matter build up. It can be incorporated in the composting process

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Soil Biology & Agriculture

Productive soils in natural environments are populated by many groups of organisms. The vast majority of these organisms are involved with organic matter breakdown & are beneficial to soil function & crop growth.

They range from microscopic bacteria to large organisms such as earthworms & beetles, & their inter-reactions make up the 'soil food web'.

The composition of the natural soil food web reflect climate, soil type, & the natural vegetation/ecosystem - grasslands are bacterial dominant while forests are fungal dominant - *[fungi better decompose woody lignified material]*

Agriculture & natural events disrupt & modify the natural food web. Main effects from agriculture being:

- Cultivation that accelerates organic matter destruction - converts it to CO_2
- Use of pesticides, fertilisers & other chemicals

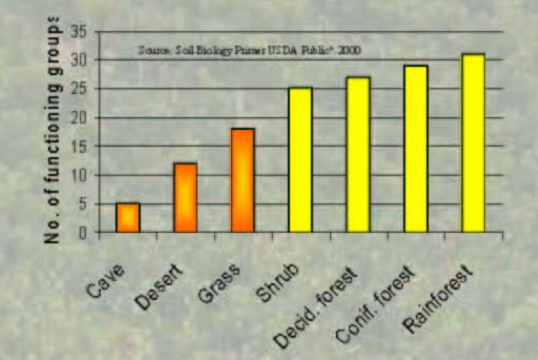
Developing more productive & sustainable production systems will be assisted by

- *The establishment of a diverse, effective food web*
- *Management practices that conserve/protect soil organic matter*

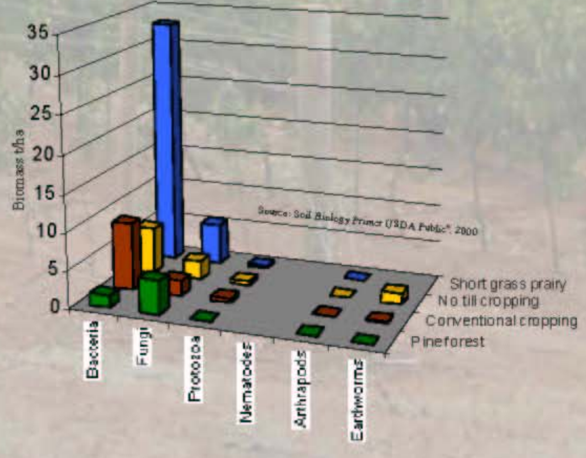
Note:

- *In many environments, a diverse potentially effective food web does not exist e.g. coarse soils of WA's Swan Coastal Plain*
- *For vegetable production on these soils, developing an effective soil food web will involve use of safe pesticide, modified cultivation, use of better rotations/break crops & physical soil modifications (addition of clay)*

Soil food web diversity in different ecosystems



Impact of management system on soil food web diversity



Soil organic matter fuels the food web & using compost therefore provides a source of organic matter as well as additional microbes that contribute to maintaining a healthy food web

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Sustainable community development & carbon based horticulture

Current situation

Landfill reduction targets recognise the need to conserve & protect finite resources, to better mange the quality of our water, soil and air and our environment

The Waste management hierarchy prioritises waste management options & underpins waste minimisation ('ZERO WASTE') strategies such as Waste 2020 in WA

The hierarchy promotes composting and related technologies because they permit safe organic recycling by managing:

- Risks of spreading pests, diseases and weeds
- Heavy metal contaminants

Waste management hierarchy

Issues for community

- Declining resource quality & agricultural impacts
- Food safety
- Availability of locally produced fresh food
- Managing waste

Issues for Waste industry

- Community objection to compost facility development
- Horticultural market development
- Planning and approval processes based on risk avoidance
- Limited focus on organic recovery

Issues for the agriculture

Global recognition of agriculture's impacts on our environment & acknowledgement that that they are largely associated with declining soil organic matter levels

Agriculture faces increasing costs due to:

- Declining soil quality and fertility
- Increasing pesticide resistance
- Declining water quality & availability

TOWARDS A SOLUTION

The re-use of composted organics in horticulture can contribute to solving ALL of these issues. To maximise these possibilities:

- Waste minimisation policies and incentives need to be fairly applied & to reflect the waste management hierarchy
- Planning & approval processes need to support a broad 'STRATEGIC' environmental objective of a sustainable society rather than risk avoidance associated with existing elements of environmental and land use legislation/strategies
- Market requirements, rather than waste management priorities need to drive organic recycling processes

Compost production and utilisation in horticulture

April 2008

Bob Paulin and Peter O'Malley
Department of Agriculture and Food

Disclaimer:

The contents of this report were based on the best available information at the time of publication. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

Summary

Maintaining and improving soil organic carbon levels is becoming an increasingly important aspect of modern farming and compost provides potentially one of the most effective ways of applying organic matter to soils and improving organic carbon levels.

It is not the only option available. Others include the use of cover or break crops, reducing the use of cultivations, selecting safe pesticides that have little or no impact on beneficial soil biology and the adoption of other practices such as permanent bed systems.

Using compost particularly in intensive industries like vegetable production has demonstrated potential to reduce the needs for fertiliser, irrigation and pesticides, and to improve marketable yields. It is also likely to extend produce quality shelf life.

Other benefits are the result of the composting process that stabilises nutrients and minimises leaching of nitrogen in particular, avoid risks of spreading pests, diseases, weed seeds that are associated with raw organic matter; reduces contaminant levels as a result of blending different feedstocks and its capacity to degrade the increasing array of organic compounds that are of concern.

In addition to potentially improving grower returns, the use of composted organic materials from both urban and agricultural sources will make real contributions to reducing carbon emissions and protecting the quality of groundwater.

The degree to which compost use can improve returns will depend on capturing the financial benefits that accrue as soil organic matter increases. It will also be important to ensure that the improved environmental outcomes for the wider community are passed on to the composting industry and the users of compost.

Cover crops apart, other forms of organic matter such as manures, while usually cheaper, they have significant disadvantages compared to compost products, including:

- nutrients that are readily leached to groundwater;
- presence of diseases as well as weeds and pests;
- smaller contributions to soil carbon and therefore to improving soil performance;
- significant fly breeding including the troublesome Stable fly; and
- odours.

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What is compost?

Compost is stable aerobically decomposed organic matter. It is a biologically active material mostly of organic origin that can vary in texture. It is typically dark brown with an earthy appearance and smell. A good example is shown in Figure 1.

Figure 1: Example of good compost.

Compost is the result of a managed decomposition process in which successions of aerobic micro-organisms break down and transform organic material into a range of increasingly complex organic substances, many of which are loosely referred to as humus. These substances are responsible for many of the important characteristics of healthy high quality soils including their ability to hold plant-available nutrients and moisture.

Compost is ideally made from a mixture of organic materials that are blended to achieve an appropriate carbon to nitrogen ratio. Regardless of the method used, the composting process is managed to maintain temperature, oxygen and moisture levels within accepted ranges.

Compost can be produced using a range of equipment from basic pile turning with front-end loaders to sophisticated in-vessel processing. However it is process management rather than equipment that determines compost quality.

Types

For horticulture, the major consideration is whether the compost is best suited to soil incorporation prior to crop establishment, or as surface applied mulch after the crop has been established.

Soil incorporation

Composts suitable for soil incorporation and production of annual crops or orchard and vineyard establishment have the most exacting quality requirements.

Good quality compost is most readily achieved with non-woody organic materials such as crop waste, straw and leafy materials. This is because the carbon in these materials is readily degraded and they develop a crumb structure that is like soil in appearance. Addition of clay materials can further enhance this characteristic.

Similar quality compost can also be made from lignified woody materials. However, because the carbon from these sources is more difficult to degrade, it can require longer processing to achieve a given level of maturity. Composting time for woody materials is reduced by increasing the level of milling or grinding because it exposes more of the carbon to microbial attack. The use of purpose-built turning equipment rather than front-end loaders will also speed up the composting process. This is because of their superior ability to break up and thoroughly mix and aerate materials within the compost pile.

Composts based on woody green organic materials can, depending on age and coarseness, contain undecomposed woody material. Soil incorporation processes, particularly involving rotary cultivators, will further break up this woody material, exposing the undecomposed material to microbial attack. The resultant increase in microbial activity increases the demand for nitrogen that can potentially compete with the crop for available nitrogen and reduce crop growth.

For this reason, woody green waste-based composts should be screened with a 10 mm or finer screen to minimise the risk of undecomposed materials being present.

Mulches

Compost marketed as mulch is normally made from a higher proportion of green waste and woody materials and will therefore have a lower nutrient content.

It may be screened to remove large particles and sometimes the finer material because the primary purpose is to provide a protective blanket over the soil that reduces moisture losses, moderates soil temperatures and reduces weed growth.

These composts are widely used in orchards and vineyards where improvements to yields without measurable reductions in fruit or grape (from a winery perspective) quality have been reported. Figure 2 illustrates how standard compost mulch applied at 50 mm depth in a 0.5 m wide strip has maintained soil moisture levels in a vineyard at Frankland in the Great Southern region of Western Australia.

Figure 2. Composted mulch trial established on 1 year old apple trees, *(Illahwara orchards).*

Pasteurised and raw mulches

To be classed as a pasteurised mulch, the composting process needs to have met pasteurisation requirements defined in the Australian Compost Standards, AS 4454 – 2003, such as achieving pile temperatures above 55°C for a minimum three days, following three consecutive turns.

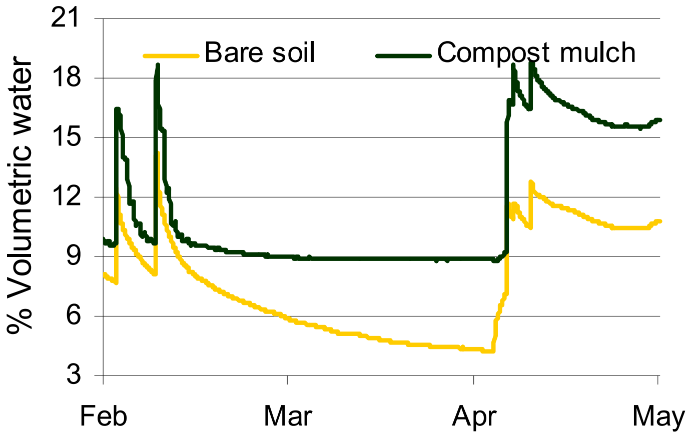

Figure 3. Soil moisture measured at 60-90 cm depth in a vineyard at Frankland.

Active decomposition associated with these materials means that the microbes, mainly bacteria, have a large demand for nitrogen. Consequently these materials have the potential to compete with crops for nitrogen, and consideration should be given to providing additional nitrogen to counter this possible effect.

To minimise growth reduction when using pasteurised mulch, minimum quality standards including C:N ratio less than 35 and a Nitrogen Draw Down index (NDI) above 0.3 are suggested. The NDI is a measures the potential for a product to compete with a crop for nitrogen.

Mulches that not satisfied pasteurisation requirements as defined by AS 4454 are likely to introduce disease, pests and weeds this is unacceptable unless they are spread within the property from which they were derived.

Spreading raw mulches has resulted in the rapid and wide distribution of a number of disease and weed problems in particular. This is totally unacceptable to agriculture, leading to increased pesticide usage and other costs associated with its management.

More important is the increased biosecurity risk posed by raw mulch as inevitable delays in detecting the arrival of a new (exotic) pest, disease or weed, mean that it can be widely distributed by the time it is detected.

This was highlighted when raw mulch was identified as a major cause of the rapid spread of a phytophthora disease, sudden oak decline, in California. This potential risk has been recognised in the new Biosecurity and Agricultural Management (BAM) Legislation in Western Australia.

Benefits

The benefits of using compost largely result from its effects on both the quality and level of soil organic matter and in its potential to increase stable soil carbon levels.

Soil organic matter

Soil organic matter is the third and arguably the most important component of our soil (Figure 4) because of its potential to improve the other two (physical and chemical) components and collectively improve most soil attributes including:

- better crop performance and crop quality;
- improved nutrient and irrigation efficiency;
- increased infiltration and reduced compaction;
- reduced nutrient leaching and increased nutrient holding
- reduced need for pesticides.

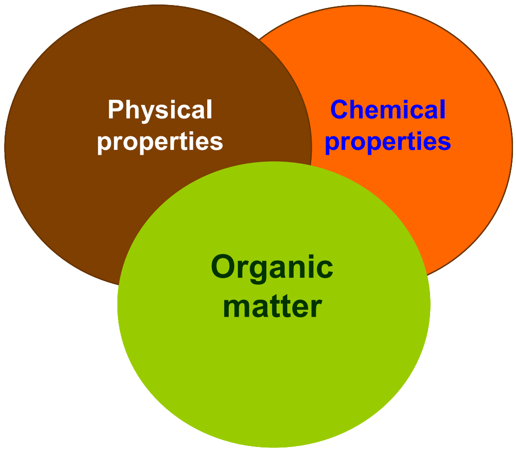

Figure 4. Three components of soil

These improvements relate to better soil quality that is the result of improved biological activity (soil health), fertility and physical characteristics that include better moisture holding and drainage, and reduced soil compaction and erosion. Increasing soil organic carbon therefore improves most if not all aspects of crop production including our capacity to address potential environmental concerns. The amount of improvement will be determined by ‘how much’ we can increase soil organic matter levels.

Soil organic matter reflects the decomposition of organic materials by the actions of vast number of soil organisms that are collectively referred to as the soil food web. These are responsible for returning organic materials to the soil and for maintaining its quality and performance. The decomposition process produces a large range of carbon based compounds including simple sugars that fuel biological activity, cellulose cementing agents that contribute to soil structure and humic substances. The humic substances play a critical role in delivering most of the above benefits associated with increased soil organic matter and ultimately they are responsible for increasing stable soil carbon levels.

This dynamic process requires regular additions of organic materials and composting not only deals with the risks associated with raw organic materials but importantly produces compost that can have a significant levels of humic substances that can directly increase stable organic soil carbon.

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Increasing soil organic matter improves soil structure, water infiltration, soil aeration, combats soil compaction and increases the soils water holding capacity. In sandy soils, organic matter increases nutrient holding capacity and is associated with increased organic nitrogen levels that can be mineralised to provide crop nitrogen. Adequate soil organic matter also counters acidification caused by most fertilisers and the associated increases in biological activity and diversity can reduce diseases and pests.

One important aspect of these active decomposition processes is mineralisation, the process that releases nutrients and in particular nitrogen for use by plants. This process enables organic systems to achieve good crop production while restricting ground water nitrate levels to environmentally safe levels, something that is almost impossible to achieve when there is low soil carbon and exclusive reliance on fertiliser nitrogen use. The use of compost will improve the capacity to produce safe ‘clean/green’ horticultural produce and importantly increase the potential for large-scale organic food production.

By reducing potential damage to soil and water resources and increasing the ability to manage nitrate-nitrogen losses to groundwater compost use should improve the security of existing soil and water resources and improve future access to additional sources.

In summary, using compost can be expected to:

- Improve crop performance and lower production costs through:
  - improved yields, product quality and storage life;
  - more efficient and reduced use of fertilisers and pesticides, including soil fumigants;
  - better utilisation of irrigation; and
  - increased crop resistance to pests and diseases.
- Improve soil quality through:
  - better organic matter levels and organic cycles;
  - increased available water to plants;
  - increased nutrient availability and nutrient-holding capacity;
  - improved structure; and
  - reduced soil-borne plant pathogens and pests.

Contribution to crop nutrition

Soil fertility is associated with mineralisation of nutrients contained in organic matter and their release in plant available form to the soil solution. Mineralisation is the result of normal biological cycles within the soil and can be stimulated by the addition of appropriate quality compost and cultivation. Because mineralisation occurs over extended periods, it can make important contributions to plant growth and to minimising the impact of leaching associated with rainfall and excess irrigation.

In biologically active soils, any available nutrients will stimulate additional microbial growth which further aids nutrient retention. The net result is that crops require less fertiliser and fewer nutrients are leached to the groundwater.

Compost is derived largely from plant materials (typically 80 per cent of the initial mix), so its nutrient content will be similar to that of most crops. The nature and ratios of the materials or feedstocks used in its manufacture will influence the nutrient content of the compost produced. Depending on the rate used, compost therefore has the potential to supply a significant proportion of a crop's total nutrient needs.

The following suggested nutrient contributions from compost to horticultural crop production are based on research findings and interpretation of overseas information. They are intended only as a guide because they have had limited commercial validation.

Nitrogen contribution

Nitrogen in compost is mainly in an organic form unavailable to most plants. This explains why most research into crop availability suggests that following compost application, only 20 to 30 per cent of its total nitrogen will be available to crops. With repeated applications, it is possible to build significant reserves of organic nitrogen, even in coarse sandy soils, and mineralisation of this organic nitrogen pool can release available nitrate-nitrogen to plants over extended periods. The level of mineralisation will vary with climate, soil type, compost type, and the size of the organic nitrogen reserve.

Nitrogen levels in compost rarely exceed 2.0 per cent and are typically in the range of 1.0 to 1.5 per cent on a dry weight basis. Based on 20 to 30 per cent of compost nitrogen becoming available to a crop following its application, 20 cubic metres of compost is likely to contribute 20 to 35 kg of nitrogen, which is equivalent to 43 to 76 kg of urea. This assumes that the compost has appropriate maturity, contains 1.25 per cent dry weight (% dw) nitrogen, has 40 per cent moisture content and a density of 0.75 tonnes per cubic metre (t/m^3).

Recent work with compost in vegetable crops initially demonstrated large increases in soil organic nitrogen, but indicated that only 10 per cent of the nitrogen was being used by the crop. Low soil nitrogen levels and poor compost quality may explain this initial low utilisation, as later work showed compost of the correct quality stimulated the release (mineralisation) of available nitrate-nitrogen to plants from both soil reserves and the applied compost.

Nitrogen-related quality criteria are listed in Table 1 and include a carbon to nitrogen ratio (C/N) of less than 20, total nitrogen above 1.0 per cent dry weight, soluble nitrogen above 100 mg/kg, with at least some nitrate-nitrogen present (nitrate/ammonium ratio above 0.14).

As soil reserves of organic nitrogen increase, significantly greater mineralisation can occur. After long-term use of compost, we have recorded mineralised nitrogen equivalent to 150 kg/ha of applied fertiliser being made available to a crop grown in coarse sand.

The great advantage of the mineralisation process is that highly soluble, and therefore leachable nitrogen, is continuously replaced. This can result in significant yield improvements, and during wet seasons the need to re-apply fertiliser to crops after rainfall is less.

Another advantage of this increased mineralisation process is to reduce nitrogen leaching. Trials have demonstrated that soil enriched with compost can produce equivalent or better marketable yield with less than half the normal mineral fertiliser use.

Phosphorus, potassium and magnesium contributions

Phosphorus

Current soil testing procedures can be used to estimate phosphorus fertiliser requirements.

Results on coarse sandy soils indicate that 40 per cent of the phosphorus applied by compost is equivalent to that applied as superphosphate.

Phosphorus content will depend largely on the feedstock used and be in the range of 0.3 to 0.9 per cent dry weight. Manures have a relatively high phosphorus content compared to plant derived organic materials and manure-based composts will be at the high end of this range while compost based on woody green material will be at the lower end.

Therefore with phosphorus content between 0.3 and 0.9% d/w, 20 m^3 of mature compost will contain 27 to 81 kg of phosphorus. Forty per cent or 11 to 33 kg of this will initially be available and would therefore replace or be equivalent to 121 to 363 kg of superphosphate. This assumes 40 per cent moisture content and a density of 0.75 t/m^3.

Potassium

The potassium contained in compost is totally available and in soils with very low cation exchange, such as coarse sands, compost will increase cation exchange and reduce potassium fertiliser requirements by up to 20 per cent after two to three applications.

Compost normally contains between 0.8 and 1.0 per cent of potassium on a dry weight basis. Research indicates that it is used 20 per cent more efficiently than potassium supplied by fertiliser.

Therefore with a potassium content of 0.8 to 1.0 per cent (dry weight), 20 m^3 of mature compost would contain 72 to 90 kg of potassium that would be totally available and after three applications would reduce fertiliser potassium requirement by 20 per cent. This would provide between 80 and 100 kg/ha of potassium and be equivalent to 193 to 240 kg of potassium sulphate initially, and 132 to 283 kg after three compost applications. Again this assumes that the compost has 40% moisture content and a density of 0.75 t/m^3.

Figure 5. Urban curbside collected greenwaste - an excellent clean feedstock for compost manufacture. *(R. Paulin DAFWA)*

Magnesium

Our work indicates that magnesium is totally available in compost and that similar effects to those achieved with potassium will apply.

Therefore with a magnesium content of 200 to 250 mg/kg, 20 m^3 of mature compost would contain 16 to 20 kg of magnesium. Initially this would be equivalent to 160 to 204 kg of magnesium sulphate and as with potassium, would increase 20 per cent to between 192 and 245 kg after three compost applications. Again, this assumes that the compost contains 40 per cent moisture and a density of 0.75 t/m^3.

Production

Compost is made from a wide range of organic materials including all plant and animal products and crop, food, manure, timber and paper wastes. Inorganic materials such as clay, fly ash (from power generation) and potentially other by products of the mining and mineral sands industries such as bauxite residue or 'Alkaloam' can also be included. These non-organic materials can be used to modify compost quality and characteristics.

Best quality compost is made from wastes that are separated at source or are a known blend of wastes such as green waste containing food. Source separated feedstocks provide blending options that maximise composting process efficiency by allowing:

- adjustment of the carbon to nitrogen (C:N) ratio and rate of biological activity;
- adjustment of porosity that assists with managing aeration; and
- reduced contaminant levels.

Composting equipment ranges from various physical turning and aeration devices to forced aeration static pile and in-vessel systems. Depending on the location and nature of the materials, composting may be carried out outdoors, indoors or within enclosed vessels. Enclosed systems are expensive to establish, but can provide maximum control over the composting process and odours.

Figure 6. Tractor-drawn windrow turner. (*Custom composts, Mandurah)*

Regardless of method and equipment, composting is an aerobic process that requires good process management to ensure and maintain:

- C:N ratio in the range of 25 to 35:1;
- adequate oxygen levels;
- moisture levels between 40 and 60 per cent; and
- temperatures below 70°C and preferably between 55 and 65°C.

Figure 7. In-vessel composting. *(Southern Metropolitan Regional composting facility, Canning Vale, Perth)*

The C:N ratio is adjusted by blending the different feedstock and values for a number of materials along with typical density and porosity ratings is provided in Appendix 1.

In addition to careful management of feedstock, producing consistent compost quality requires regular monitoring of temperature, moisture, and oxygen levels. Too hot and it will destroy the composting micro-organisms, too cold and it will be insufficient to destroy diseases, pests and weed seeds.

Adequate moisture is also important as the activity of microbes will decline when moisture levels drop below 40 per cent. The hand squeeze test can be used to estimate moisture levels, adequate moisture is indicated when some moisture appears can be squeezes from a handful and it is too dry if the material falls apart when the palm is opened. As moisture

Figure 8. Static pile composting involves aeration with forced air. ***(Biowise composting facility, Medina).***

content increases above 60 per cent, the risk of low oxygen or anaerobic conditions increases rapidly, resulting in longer composting time and the potential for reduced quality.

The use of coarse-textured feedstocks to improve porosity will make it easier to maintain adequate oxygen levels.

Figure 9. Regular monitoring essential for consistent compost quality. ***(Custom Composts, Mandurah, WA).***

Composting involves two critical stages that are characterised by the temperatures achieved within the composting pile or windrow. Figure 5 represents an ideal in-vessel or static pile system where continuous management of conditions makes it possible to maintain steady temperature. In windrow composting, regular turning results in temperature decline followed by recovery as the composting process re-establishes itself.

Composting stages

1st stage *High temperature (thermophyllic) phase.* Temperature exceeds 55°C but needs to be maintained below 70°C by turning and forced aeration.

Conventional outdoor composting usually requires six to eight weeks and regardless of the composting method, should be greater than three weeks (see Figure 10) considered to be the minimum requirement for in vessel processes.

This stage culminates in the production of stable compost that can be stored safely. It is the period of greatest volume reduction.

Effective pasteurisation and control of diseases, pests and weeds will occur if temperatures above 50-55°C are maintained for four to five days. The beneficial microbes that are responsible for the composting process can survive temperatures up to 70°C.

Well managed aerobic composting generates temperatures that kill the disease, pest and weed contaminants that can be present in organic materials. A quirk of nature is that the organisms that decompose organic materials can survive these temperatures. In windrow composting, the conditions need to be achieved over a minimum of three turns to ensure that all the material is effectively pasteurised and therefore safe to use. These conditions are defined in the Australian Standard for compost, soil conditioners and related products (AS 4454).

With the completion of the thermophyllic phase, the composting material stabilises, meaning that it can be considered to be compost. At this stage, the composting temperatures and more importantly, the production of carbon dioxide or the consumption of oxygen have begun to decline.

2nd stage *The cooling or maturation (mesophyllic) phase.* As maturation progresses, the core temperature of the composting pile continue to decline and will eventually reach ambient temperatures.

By definition, compost must have achieved stability, however it will still be too immature for use in many situations and generally should be further matured. Composts that are relatively immature provide greatest nutritional benefits and highly matured compost have higher humus levels and deliver better outcomes in terms of soil quality.

Continued management is important throughout the maturation phase. Techniques for measuring compost maturity and therefore its potential value are not well developed.

Nitrogen is required to increase microbial activity that degrades or breaks down the carbon-rich organic materials such as straw, crop waste and green waste. Nitrogen is usually derived from manure, however a number of fresh, green/leafy organic wastes and food wastes have adequate carbon to nitrogen ratios for them to compost without the addition of extra nitrogen.

Feedstock selection and blending ratios are used to achieve optimum C:N ratios of between 25 and 35. High nitrogen levels (or low C:N ratio) accelerate microbial activity and maintaining temperatures below 70°C becomes difficult. This situation also results in nitrogen losses. If nitrogen levels are too low, the composting process will be slowed and may fail to achieve adequately pasteurisation.

When determining C:N ratio of the materials to be composted, consideration needs to be given to carbon availability. With woody materials, the total amount of carbon present determined by analysis is much greater than the amount immediately available to the composting process. The available carbon is the proportion that is exposed to microbial attack.

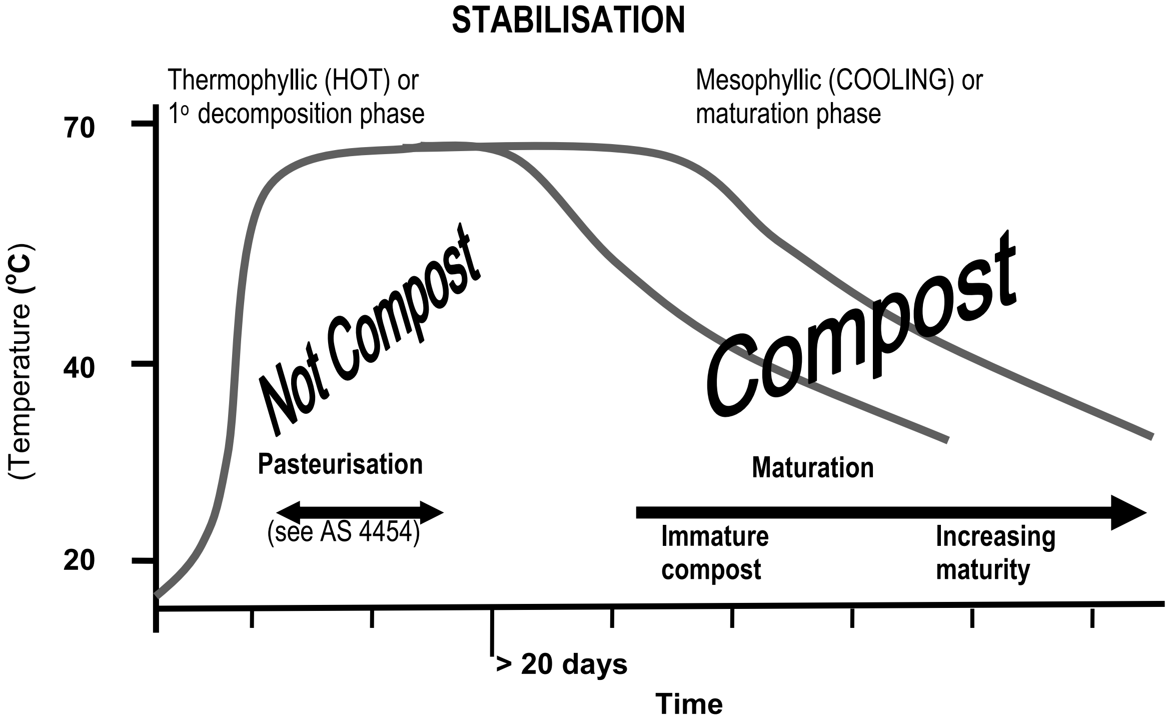

Figure 10. Temperature changes during in-vessel and static pile composting process.

Storage

Composting is a continuous process. Therefore maintaining a given maturity or quality requires biological activity and storage time to be minimised.

The biological activity depends on moisture levels, so allowing compost to dry out will permit storage with minimal change to the quality.

When storage is required, continue turning the compost without any addition of water until moisture levels approach 30 per cent, then push it into large heaps and leave without further turning. Ideally it should be re-wet prior to marketing in order to minimise dust during spreading.

Quality

Compost quality is complex and is related to the intended use of the final product.

Aspects include consideration of its maturity, type, nutrient content and levels of contaminants. Useful measures include the C:N ratio, total and available nitrogen including the nitrate to ammonium ratio, and Nitrogen Drawdown Index (NDI).

Potential contaminants include disease, pests and weeds, inert materials such as plastics in all its forms, metal, glass and heavy metals.

Many heavy metals are important crop nutrients and compost often contains substantial levels of zinc and copper in particular. This is beneficial to many Western Australian soils that are typically deficient in the elements. However if compost with copper and zinc levels approaching 100 and 200 ppm respectively are applied regularly, it would be advisable to test soil levels periodically to ensure that they do not become potentially toxic to crops.

Compost processes minimise these risks and quality assurance systems ensure that the risks are managed within acceptable limits. Most professional compost producers will have a quality assurance system and preference should be given to those that are independently audited.

Stability and maturity

Stability defines the completion of the initial thermophyllic phase of composting (Figure 5) and is a prerequisite for a compost product to be called compost.

Maturity reflects the level to which the second (mesophyllic) stage of composting has proceeded (Figure 10). Maturity is the single most important determinant of compost quality because of its influence on crop yields and quality. Humic substances develop during maturation and the time required to reach a particular stage of maturity depends on the feedstocks and the process used, woody materials generally take longer.

Measuring maturity is not simple and a consistent conclusion from extensive research is that it cannot be defined by a single measurement. The compost maturity index (Cotton 2002) evaluated in vegetable production (Buchanan 2002) for the Californian Compost Quality Council (CCQC) has considerable promise. The index is derived from the C:N ratio, together with a measure of toxicity, such as seedling root growth and a measure of stability, such as carbon dioxide production.

The index gives compost a maturity rating between 1 (immature) and 5 (highly mature). Validation field studies indicated that for vegetables, index values around 2 gave the best results, particularly in terms of contributions to soil fertility.

Prior to commencing local research, we used earlier work and the literature to define a set of quality requirements (Table 1) for compost to be used in vegetable production. Comparing results over 18 trials against compost performance suggested that C:N ratio and various measures of nitrogen were most consistent indicators of the best compost for vegetable production.

An asterisk in Table 1 indicates these ideal values and it is likely that collectively they result in greater mineralisation of plant nutrients and in particular, increased crop-available nitrogen. The type of plant-available nitrogen present is also important and some nitrate nitrogen needs to be present as indicated by a nitrate to ammonium ratio greater than 0.14. The potential for compost to compete for nitrogen, measured by the NDI, can also be a useful indicator of compost quality but is a relatively expensive analysis to perform.

Table 1. Critical analysis values, conducted to Australian Standard AS 4454 and based on DAFWA's compost research and development program

Measurement	Value	Unit	Comment
* Carbon to nitrogen (C/N) ratio	<20.0*	-	For crop available nitrogen
Nitrogen Drawdown Index (NDI)	>0.5	-	Lower values likely to compete for crop N
* Total nitrogen	>1.0*	% DM	
* ammonium plus nitrate nitrogen	>10.0*	mg/L	Also indicates nitrogen availability for crop
* nitrate/ammonium ratio	>0.14*	-	High ammonium level indicates immaturity
Organic matter	>35.0	% DM	Higher the better
pH_{Ca} (measured in calcium chloride solution rather than water))	5.0-7.5		Ideally around 7.0
Electrical conductivity	<60.0	mS/m	Equals 6 dS/m
Toxicity (potting mix test)	>60.0	%	Low levels indicate insufficient composting
Moisture content	>30.0	%	Ideally around 40%

* critical values indicating that compost is likely to be suitable for vegetable production

Applying compost

Rates, timing in relation to crop establishment and placement are all factors that can influence results. Traditionally compost is broadcast and incorporated close to planting, however when compost is immature and likely to create problems with establishment, such as with small seeded crops like carrots, then allowing 10 to 14 days will minimise potential problems.

Strategies for efficient use

Maximum benefits from compost require regular, repeated use.

As soil organic matter levels and microbial populations develop, significant reductions in fertiliser, irrigation and pesticide applications will be possible. Soil organic carbon levels are influenced by:

- soil type - they are lower in light sandier than heavier soils;
- management - cultivation in particular reduces levels; and
- climate - lower in dry arid and war m humid climates.

Improved performance achieved with sandy soils on the Swan Coastal Plain, have been associated with increasing organic carbon levels to around 1 per cent on a dry weight basis. However it is generally accepted that to fully achieve potential benefits and in particular to maximise irrigation savings, levels need to approach 2 per cent in our sandy soils.

Suggested rates for using compost and mulch compost in various horticultural crops are provided in Table 2. For vegetable production on light sandy soils, trials and commercial experience suggest that rates in the order of 20 to 25 m^3/ha are sufficient to achieve significant results. Reduced volumes by either banding (Figure 11) or restricting placement to the planting beds (Figure 12) is likely to maintain or even improve crop establishment but is unlikely to achieve the same increase in soil carbon.

In the longer term, it is feasible that lower rates of 10-15 m^3/ha/year will be sufficient. However, it must be stressed that rates will be determined by the adoption of management practices that promote soil organic carbon levels and the maintenance of effective soil organic cycles. These include reduced cultivation, greater use of cover or break crops, as well as minimising the use of pesticides, fertilisers and other practices that disrupt beneficial microbial populations.

Figure 11. **Specialised placement of compost.**
(Courtesy Custom Composts).

The addition of clay, either directly or as a component of compost, will also assist organic matter build-up. This is because of its positive influence in creating a wider range of pore sizes that in turn provide a more protective environment for the important microbial component of the soil biology, the 'soil food web'.

Table 2 provides a preliminary guide to selecting compost for either soil incorporation (vegetable production and orchard/vineyard establishment) or application as surface mulch.

Note that the values provided in Table 2 are recommendations based on our collective knowledge and the results of trials over extended periods in which crop levels and compost analysis have been compared.

Figure 12. **Compost applied only to planting bed.**
(Courtesy Custom Composts).

Table 2. Suggested rates and critical quality factors for using compost in horticulture

Factor	Soil incorporation		Surface mulch
	Vegetables and annual crops	*Orchard, vineyard and perennial crop establishment*	*Orchards, vineyards and perennial crops*
C:N (carbon to nitrogen) ratio	<17	<20	Not as critical, prefer <35 to minimise N competition
NDI (Nitrogen Drawdown Index)	>0.6	>0.5	Not critical, prefer >0.3 to minimise N competition
Electrical conductivity (mS/m)	<60.0	<80.0	<80.0
pH	6.5–7.5	6.0–8.0	6.0–8.0
Moisture content (% dry matter)	>35	>35	>35
Total nitrogen (mg/kg)	>1.5	>1.0	Not critical, prefer >0.7
Soluble nitrogen (mg/kg)	>100	>100	Not critical
Nitrate/ammonium ratio	>0.14	>0.14	Not critical
Toxicity %	>60	>60	>30
Application rate, suggested typical range	15-30 m^3/ha	25-75 m^3/ha trenched into planting rows	50-75 mm depth to 15-25% of land centred on the row

Markets

In any situation, the success of composting will be determined by the balance between production costs and the returns from the benefits provided. Costs include raw material assembly, processing, distribution and spreading. Returns need to reflect the benefits to the user together with recognition of the contribution that compost use makes to the environmental costs of managing organic wastes.

Compost user benefits need to reflect all of the benefits associated with improvements to soil performance including soil fertility and health (savings in fertiliser and potentially pesticide use), irrigation and benefits from reduced erosion from both rain and wind. The wider environmental benefits to organic waste management need to include contributions to managing soil and water quality and to reducing carbon emissions.

Agriculture is widely regarded as one of the major compost markets and its development was the motivation for the National Compost Roadmaps program that was established in 2003. Around the world agricultural use of compost varies enormously and the success usually reflects the market development approaches adopted. Invariably quality and applied cost relative to measurable returns are the main determinants of progress and overall this market continues to be poorly developed. California is a notable exception as is the viticultural industry in South Australia, particularly around Adelaide.

The reality is that the regular use of appropriate quality compost will increased returns. These improvements will increase over time. However it will be essential for farmers to make adjustments to management that translate the benefits into better returns.

Compost production has grown significantly in recent years and this growth is likely to accelerate in coming years. Production is largely based around Perth where a number of companies produce composts from a range of agricultural and metropolitan waste streams.

Factors such as increasing landfill reduction targets, increased landfill levies and restrictions on the use of raw manure are likely to increase compost use.

Compost is being used in a wide range of horticultural crops and some broadacre crops, as well as domestic and commercial landscape situations. Revegetating land following mining and road construction, and remediating contaminated sites are other markets with potential to grow.

Horticulture, with its relatively intensive nature and potential for continued strong growth is a very important market. However, this growth is being limited by concerns about compost quality, limited knowledge of both its benefits and how best to use it and its cost that is typically incurred before crop establishment.

Many horticultural industries, especially vegetable production, have the added advantage of being close to population centres that generate large volumes of feedstock for compost manufacture. Ultimately compost use by horticulture and agriculture will be dependent on accessing adequate quality feedstocks from urban centres.

The compost industry has been well served by the Australian Standards for compost and related products (AS 4454), however they do not address specific requirements of the various market sectors. Recognising this, Compost Australia, the National Recycled Organics group within the Australian Waste Management Association (WMAA) is developing quality standards and minimum information requirements to facilitate purchase of products that are appropriate to the intended use.

Use in vegetable production

Work with compost in vegetable production has demonstrated its potential to substantially improve soil quality and performance by increasing soil organic carbon levels. As shown in Figure 2, without the addition of compost, organic matter levels tend to decline. Its impacts on a range of soil quality measures are shown in Table 3.

Management, soil type and climate influence soil organic carbon levels and these will ultimately determine how much compost is needed to maintain healthy, functional soils.

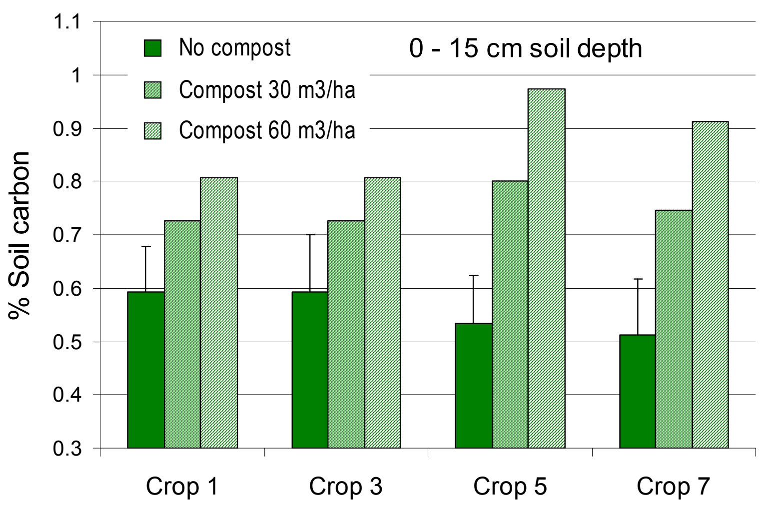

Figure 13. Changes in soil carbon levels over seven consecutive crops at the Medina Research Station.

The use of compost in horticulture has the potential to make significant contributions to the continuing growth of these industries. In addition to improving yield and reducing fertiliser, irrigation and pesticide inputs, compost can minimise the adverse affects of continuous intensive cropping on soil performance and water quality.

Maximising the benefits of compost to horticultural productivity and sustainability requires repeated use, fertiliser adjustment to accommodate nutrients supplied and improved soil quality / performance, and changes to production practices.

The range of improvements to soil performance indicated in Table 3 are generally influenced by the compost application rate and apart from increased soil moisture holding include:

- reduced bulk density, results in increased soil aeration and potential crop root growth
- increased cation exchange capacity (CEC) or the ability to hold cations such as calcium, potassium and magnesium. This improvement explains the 20% reduction on potassium requirement associated with compost use;
- modified pH. Compost and increased soil carbon tends to maintain soil pH in the neutral range that suits most crops; and
- total nitrogen – the use of compost is associated with considerable organic nitrogen reserves and therefore the potential release of plant available nitrogen along with reduced leaching risks.

Table 3. Soil properties at the Medina Vegetable Research Station after seven compost applications

Treatment	Soil carbon (%)	Volumetric water (%)	Bulk density (t/m^3)	CEC (c mole/kg)	pH $_{CaCl2}$	Total N (%)
Control	0.51	10.12	1.429	2.71	5.85	0.027
Compost @ 30 m^3/ha	0.75	11.99	1.365	6.17	6.80	0.048
Compost @ 60 m^3/ha	0.91	14.17	1.321	8.53	6.85	0.065
LSD*	0.10	0.41	0.023	1.08	1.79	0.005

* Least significant difference – the minimum difference between values that can be considered statistically different at the 5% level of confidence.

Compost use has produced the most consistent improvements with broccoli (Figure 14) and lettuce (Figure 15). With carrots, improvements have tended to be small and variable. However in the most recent work with carrots, reducing normal nitrogen applications resulted in significantly improved marketable yields (Figure 16).

This improvement to marketable carrot production is most likely to have been the result of improved soil quality and the associated increases in soil nitrogen reserves, however the benefits were achieved when we reduced nitrogen rates, emphasising the importance of maintaining correct soil nutrition.

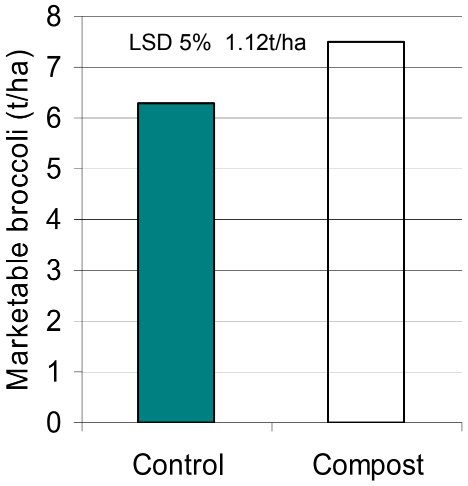

Figure 14. Increased broccoli yield with 30m^3/ha compost.

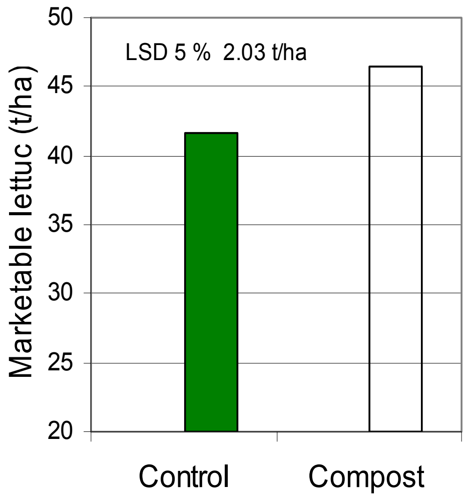

Figure 15. Increased lettuce yield with 30 m^3/ha compost.

This result also supports the potential for improved soil quality associated with compost use to maintain production levels and reverse widely experienced trends for declining carrot yields over successive cropping cycles.

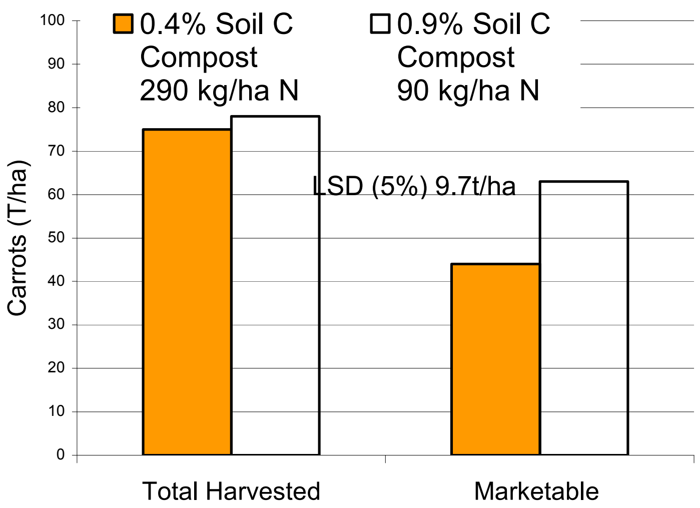

Figure16. Impact of compost use together with adjustment in nitrogen application on carrot yield.

Use in fruit and vine crops

Most of the work in fruit and vine crops has involved the application of compost mulches or the use of compost in orchard and vineyard establishment.

Improved citrus, avocado and apple tree establishment has been achieved when good quality compost has been incorporated in the root zone at planting.
Improved tree growth and yields have also been recorded for apples and both table and wine grapes, although levels of improvements were generally not as large or as consistent as had been recorded in South Australia (Buckerfield and Webster).

In situations of limited water, mulches have demonstrated a capacity to better conserve and utilise available soil reserves (Figure 1). This affectcombined with lower water avaialbility is a likely explanation for the generally better results achieved in South Australia (Buckerfield and Webster).

The use of compost and compost mulches in fruit and vine crops will be of most benefit when growing conditions are less than optimal and particularly when water availability is restricted. Their strategic application to areas where soils are not as good or to poorer performing areas can be used to improve uniformity and hence overall orchard and vineyard performance. Suggested application rates for the use of compost and mulch is provided in Table 2.

Cost considerations

The overwhelming conclusion from our results over almost 10 years is that the use of compost improves returns.

Fertiliser savings are the major immediate gain that growers can make when using compost. Based on least cost fertilisers, the savings detailed in the crop nutrition section, to principally phosphorus, potassium and magnesium requirements, will cover at least 60 percent of an applied compost cost of $40/m^3.

Based on recent work, percentage increases in yield necessary to cover costs of applying 25m^3/ha of compost at $40/m^3 and allowing for $20/m^3 fertiliser savings are provided in Table 4. The indicated yield increases are within those achieved in vegetable trials at the Medina Research Station.

The current applied cost of compost, suited to use in vegetable production is $35 to $45/m^3, depending on source, volume and transport requirements. Factors such as increasing fertiliser costs and increasing landfill levies on the disposal of organic wastes are likely to make compost more competitive in future.

Table 4. Percentage increase in yield necessary to cover the cost of applying 25 m^3/ha of premium grade compost to selected vegetable crops

Crop	Marketable yield	Unit	Market return $/unit		% yield increase to cover cost of compost	
			Low	*High*	*Minimum*	*Maximum*
Lettuce	3,800	Crates/ha	5.00	10.00	1.2	2.9
Broccoli	12,000	kg/ha	0.75	1.00	4.6	6.1
Carrots	71,550	kg/ha	0.50	0.75	0.7	1.2

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Attachment 1. Compost feedstocks - typical C:N, density and structure ratings

Name	Density (kg/m^3)	Structure rating (1 to 4)*	C:N ratio (xx:1)
Bark, Hardwood	534.00	2	125
Bark, Softwood	415.33	2	135
Cardboard, Dry	148.33	1	520
Corn Stalks	124.60	1	40
Grape, Pumice	712.00	2	27
Grass/Alfalfa Hay	109.77	1	35
Hay, Dry Bales	124.60	1	30
Hay, Rough Grass	103.83	1	95
Hay, Round Bales	178.00	1	25
Hay, Grass Green	109.77	1	46
Olive pumice	700.00	3	70
Paper, Newsprint	296.67	3	400
Peat Moss	148.33	3	64
Pine Needles	118.67	2	110
Pine wood Shavings	356.00	1	350
Sawdust, Dry	256.32	3	365
Sawdust, Dry hardwood	237.33	3	996
Straw, Oat	118.67	1	120
Straw, Wheat, loose	118.67	1	120
Trimmings, Shrub	676.40	3	55
Trimmings, Tree	255.13	1	30
Woodchips, Hard	415.33	2	430
Woodchips, Soft	356.00	1	500
Yard Waste	332.27	2	44

* Structure rating is a measure of materials porosity where 1 is porous and 4 is very dense.

DISCUSSION PAPER - Compost production for agricultural use – issues for the developing recycled organics industry

R. (Bob) Paulin – Department of Agriculture, Western Australia, September 2005

Purpose

This paper is intended to stimulate discussion and foster greater understanding of the issues and considerations that are necessary for the development of agriculture, and in particular horticulture, as a significant market for the recycled organics industry.

Courtesy of Custom Composts, Nambeelup,WA.

This document reflects almost ten years' work by the Department of Agriculture, Western Australia that has increasingly recognised the essential role that soil organic matter plays in the development of 'best practice' production systems.

The benefits of compost in terms of crop production, soil fertility and the environment have been widely reported. Considerations include market development, compost quality, the development of a common understanding and consistent use of terminology, feedstock and process management, the need for policy and regulation, the potential synergies between agriculture and the wider community and the limitation associated with current application of land use planning process.

Executive summary

The numerous benefits of using compost in a range of horticultural crops have been extensively reported and this discussion paper considers factors that are limiting the development of these industries as significant sustainable markets for compost derived from urban and agricultural organic wastes.

While market development and product quality have and continue to be the focus for the compost industry, the lack of appropriately focussed policy to support and facilitate market growth is being increasingly acknowledged as the key limiting factor.

It is argued that the process of successfully recycling organic wastes needs to be supported by strong over arching policy that recognises the critical importance of soil organic matter in both the management of our soil and water resources, and our organic wastes. The findings of our extensive research and development programs unquestionably validate the importance of recycling our organic wastes through land application and in particular to the more intensive horticultural industries.

This approach will provide a framework within which existing policy and regulations can be modified and new ones implemented to bring about effective recycling of organic wastes and maximise the potential benefits. Key elements of this include regulations implementing minimum standards that will meet public health, including fly breeding, environmental and biosecurity requirements for the application of all organic materials to land.

It is also argued that retaining horticultural industries adjacent to urban centres in particular, needs to be given greater recognition. Minimising the costs of recycling both organic waste streams that include reclaimed or reprocessed water, maintaining capacity to provide best quality fresh food and contributions to a range of other benefits for society are key reasons why land use planning paradigms that prioritise urban development, need to be challenged. Requiring the 'Property development industry' to account for the broader strategic needs of our society in terms of fresh food production, responsible waste management, environmental protection and other community benefits, will make the intentions of the recently established Statement of Planning Policy for the protection of productive agricultural land, more achievable.

Cost competitiveness with a number of raw organic products including manures and raw mulches is a major barrier to developing the horticultural market for compost products. Establishing a need to process all organic materials in order to achieve safe minimum application standards will assist composted products to compete on the basis of performance rather that least cost. Other considerations include setting an appropriate balance between cost to the waste producer and product price in order to create a demand driven rather than the current largely supply driven market.

Product quality is critical to market development, and apart from facilitating, but NOT regulating product quality, issues associated with feedstock collection and management along with removal or management of contaminants such as improved chemical collection, requirements for new chemicals and pesticide registration to include biodegradability within composting processes, and mandating the use of compostable polycarbonate plastics based on cellulose rather that hydrocarbons are considered.

Introduction

Considerable progress has been made with developing a better understanding of the factors that influence compost quality and therefore its performance and fitness for purpose.

Product quality and wider recognition of the benefits from compost use have increased, however progress with developing the agricultural market for compost has been hampered by its cost, particularly in relation to other organic wastes such as animal manures, and inconsistent quality.

Concerns about the a potential for increasing production of composts made from Municipal Solid Waste (MSW) to reduce continued market growth, have also emerged.

Landfill diversion targets have given way to the broader and more useful concept of zero waste and the 'Waste Hierarchy' provides general guidance on relative priorities of options for managing wastes. However the level of market development coupled with anticipated growth in compost production is increasing concerns that significant quantities of potentially valuable organic 'waste' resources will be diverted to energy recovery.

It is accepted that composting (recycling organic materials) represents a higher order use of the organic 'waste' resource than energy recovery. The need to provide the organic recycling industry with at least equivalent financial incentives to the renewable energy credits available to the renewable energy sector is also considered.

While organic diversion processes are in place, there is a lack of policy and appropriate regulations to drive the marketing of compost and the Recycled Organic Products in general.

Finally the dominance of urban growth in land use planning processes are threatening to impact on the ability of urban centres to effectively engage with appropriate sectors of agriculture such as intensive horticultural production, in managing the recycling of their organic wastes. This is already the case in Sydney where recycled organic products have to be transported considerable distances.

Issues considered therefore include:

- compost market development in agriculture - impediments to growth;
- compost quality and maturity - determining compost quality and 'fitness for purpose';
- terminology - the use and meaning of words commonly used to describe the composting process and product quality;
- the Waste Hierarchy – achieving 'zero waste' and clarifying component definitions;
- policy, regulation and standards – what is needed to underpin market development;
- source separation - compost quality and mixed waste composting;
- building linkages between agriculture and the community – land use planning, the soil fertility cycle and sustainable society.

Considerations

Agricultural compost market development:

Recognition that *a*griculture is potentially a major compost market has resulted in the national 'Compost Roadmap Project' focussing on this market sector.

Of the agricultural markets, horticulture and particularly intensive vegetable, vine and fruit growing offer the most potential because of their intensive use of inputs (fertiliser, irrigation and pesticides) and their usual proximity to urban waste generation.

Improvement to the bottom line from compost use in these crops is widely demonstrated (Paulin 2004); however they are often relatively small and are dependent on savings associated with reduced fertiliser use.

The benefits associated with improved soil quality are not realised immediately and require regular use of compost. Further, potential savings from reduced pesticide use is widely accepted but has yet to be consistently achieved on a large scale. Maximising the future economic benefits of using compost will require the development of production system packages that focus on better managing soil organic matter and consequently soil performance. Present difficulties include:

- raw manures, biosolids and shredded green waste compete directly at prices that are not achievable for composted products;
- most growers are unable to adjust fertiliser programs to achieve potential fertiliser savings when using compost; and.

- soil management in vegetable production and other intensive annual crops is highly damaging to soil organic matter and quality.

Difficulties with developing agricultural compost markets, particularly in the short term, are therefore associated with its cost and our still limited understanding of how it can be used to best advantage. Consideration therefore needs to be given to making the use of compost more attractive to growers.

Compost quality and maturity

Compost maturity is a major factor in determining compost quality and its best use. It reflects the degree to which the second Mesophylic composting stage (Figure 1) has progressed.

There are large volumes of research into compost maturity and a consistent conclusion is that it cannot be defined by a single measurement. Recent work to develop a compost maturity index by a group led by Dr Marc Buchanan (Buchanan 2000) for the Californian Compost Quality Council (CCQC) has considerable promise.

The CCQC compost maturity index involves three tests that include the Carbon:Nitrogen ratio, one test for potential plant toxicity (germination, Ammonium Nitrogen level) and one for compost stability (rate of oxygen uptake, carbon dioxide production, and reheat test). Based on critical values from each of the tests, the compost is given a maturity score/rating between 1 (immature) and 5 (highly mature).

Determining compost maturity will aid consistent performance and market development.

This index has been validated in trials using commercial composts in commercial vegetable production in the Salinas Region of California. This work indicated that composts at the lower end of the maturity rating scale are most likely to improve crop performance. The potential importance of this maturity index is to provide a quantitative measure of maturity that aids production of consistent quality compost.

Composts made with woody wastes as a significant component of the feedstock present additional considerations. Decomposition of woody lignified materials during the initial decomposition phase is limited because the microbes responsible are principally bacteria and they can only act on the exposed surface carbon. Unless time is not a concern, the production of compost from woody feedstock needs to involve the use of compost turners that continuously agitate and break up woody particles and screening to remove larger fractions that contain undecomposed carbon. Undecomposed carbon has the potential to out compete crops for available nitrogen, resulting in nitrogen draw down and reduced crop production.

With conventional windrow composting, the normal expectation is to produce compost suitable for use in vegetable production within 10 to 14 weeks. Our work in WA, supported by the findings of a recent tour of compost production in California (Paulin 2002, 2002A) indicate that this is achievable with screen sizes in the order of 10 mm.

Terminology

A Recycled Organics Dictionary and Thesaurus of terms associated with the Recycled Organics industry has been produced by the Recycled Organics Unit at the University of NSW. See the link: www.recycledorganics.com.

Composting is the process that produces compost, a stable safe to use product that is the result of aerobic high temperature (> 55°C) decomposition.

It is currently in its second edition (August 2002) and changes are suggested to the terminology of composting, products, feedstock and markets. These are summarised in Table 1 and detailed in appendices 1 to 4 respectively.

Basic composting terminology and critical stages of the composting process and its management are outlined in Figure 1. The two stages of the composting process are well accepted, namely the initial primary decomposition phase (Thermophylic or 'hot' stage) and the second maturation phase (Mesophylic or cooling stage).

The initial Thermophylic phase provides pasteurisation and the necessary requirements for this is defined by a set of minimum temperature by time conditions that need to be applied to the entire composting mass. In conventional windrow composting, this is achieved by achieving the conditions, as defined in the Australian Standard for Compost, Soil Conditioners and Mulches (AS-4454), after a minimum three turns. In California, a minimum five turns is recommended.

Table 1. Outline of suggested changes to ROU Recycled organics dictionary – see Appendices 1-4 for detail

Term or subject	Critical comments
Composting terminology - Appendix 1	
Composting	A process that is NOT time bound!
Maturation	Determines quality and fitness for purpose.
Maturity (of compost)	Relates to the second composting stage.
Stability (of compost)	Critical to defining compost.
Product terminology - Appendix 2	
Compost	Include stable/safe to use product.
Compost mulch	Amalgamate fine/coarse mulch – arbitrary, unnecessary division.
Pasteurised Recycled Organic product	'Recycled Organic' added to description.
Pasteurised mulch	Amalgamated with fine categories – an unnecessary division.
Soil conditioner	Modified description – NOTE compost included in categories.
Other products	Manufactured soil, potting mix, playground surfacing added.
Feedstock terminology - Appendix 3	
Biosolids	Incorporated into sludge category – need to reduce its 'bad' connotations!
Food organics	Comment on recalcitrant materials.
Garden organics Garden Woody organics	Replace with Green and Woody green organics – Garden is not a universal term and unlikely to be acceptable to agriculture!
Sludges, liquid - watery waste	To include biosolids.
Market terminology – Appendix 4	
Horticulture – Annual Perennial	Annual crops - major market for compost. Composted mulch important to Perennial crops.
Agriculture	Broad acre and tree crops (Silviculture).
Urban amenity	Domestic, landscaping, nurseries, sport and recreation.
Rehabilitation	Revegetation, restoration, landfill cover.
Enviro/bio- Remediation	Contaminated sites, storm water purification.

To be called compost, a product of a composting process must achieve stability. Stabilisation is the interface between the two primary composting stages.

Figure 1 defines stabilisation as the junction between the two stages of composting and defines the point at which the composted materials can be termed compost. The achievement of stability is largely determined by process management and feedstock. It is unlikely that stabilisation, and therefore the production of compost can be achieved in less than 20 days (Ed Stentiford, University of Leeds, UK, personal communication).

Further, this minimum period can only be achieved in closed composting vessels where continuous precise management of moisture, temperature and oxygen levels are possible. The variation in time to achieve stability is diagrammatically depicted by the shaded area in Figure 1.

Note that Figure 1 depicts enclosed vessel composting and does not show temperature fluctuations associated with turning compost piles or windrows.

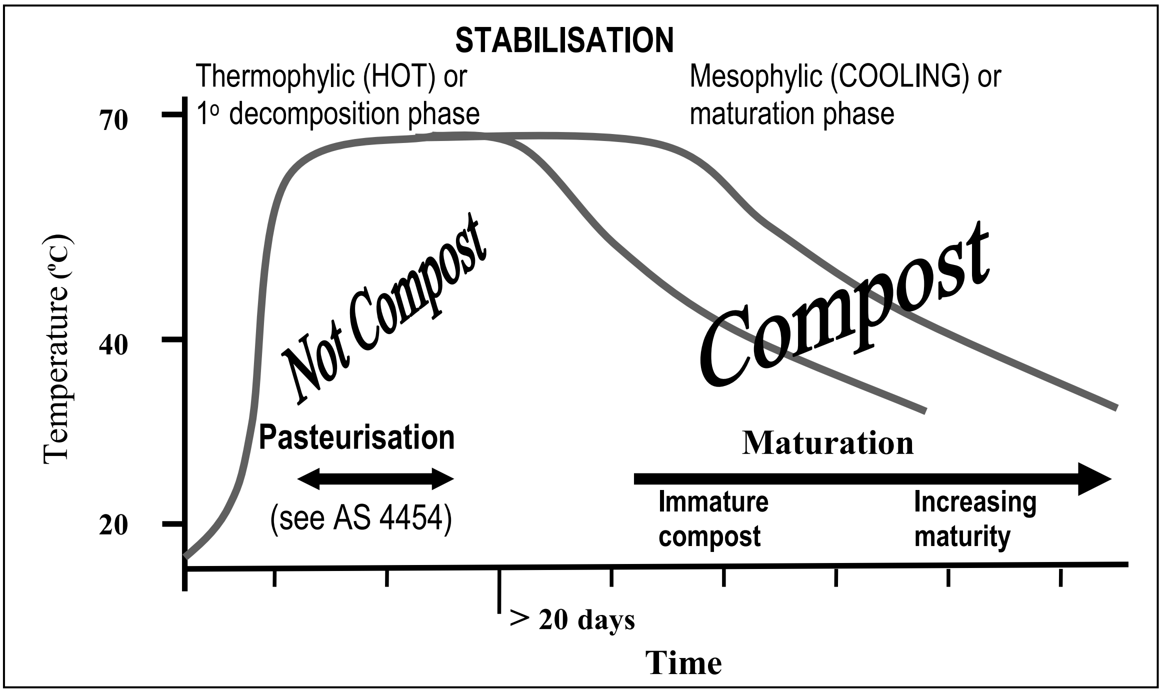

Figure 1. Diagrammatic depiction of an in-vessel composting process.

Management of the second 'maturation' composting stage is CRITICAL to final quality of compost.

The second Mesophilic composting stage is characterised by declining temperatures and is the important maturation phase of the composting process that determines how it will be best used, or its 'fitness for purpose'.

This maturation phase requires continued management and in particular, the maintenance of adequate moisture and oxygen levels within the composting mass. Compost quality will be compromised when this phase of the overall composting process is inadequately managed.

The Waste Hierarchy

The waste management hierarchy usefully defines relative preferences between options for managing wastes. In respect to organic waste, it has in the past at least, clearly identified composting as a more beneficial reuse than energy recovery.

Assigning a 'greater best use' value to composting recognises that it allows for the safe reuse of organic waste and acknowledges that compost provides a number of additional advantages that are associated with its contribution to increased soil quality and performance that increases to soil organic matter bring about.

More recently, the 'Strategic Directions for Waste Management in Western Australia (August 2003) described the hierarchy as Avoid, Minimise, Recycle, Treat and Dispose (Figure 3). The text clearly stated that composting, but not energy recovery is considered to be recycling.

It is acknowledged that the term Treat(ment) covers the entire waste stream. However when discussing the waste hierarchy in relation to organic materials, it would be preferable to use the term 'Energy Recovery' instead of 'Treat' (Figure 4) because of the possibility that composting could be regarded as a treatment. Any concern about the positioning of hybrid composting energy recovery systems would be better served by this approach as well as it is clearly positioned between the two options.

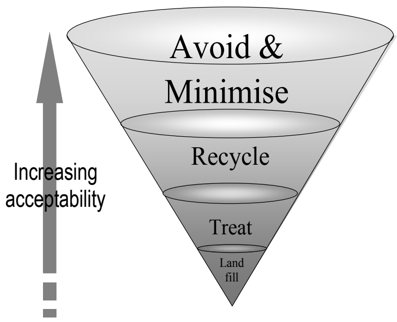

Figure 3. Current hierarchy -'Strategic Directions for Waste Management in WA' 2003.

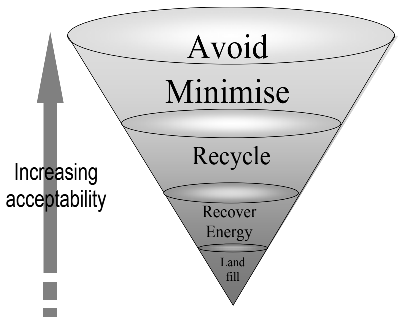

Figure 4. Preferred hierarchy - includes energy recovery.

This approach will better support the development of composting and other equivalent processes as the preferred methods for managing organic wastes

Policy, regulation and standards

Diversion of wastes from landfill commenced some time ago and although agriculture was identified as a potential market for the significant organic component of the waste stream from the outset, strategically focussed efforts to develop this market have only just began.

In July 2004, the National Compost Roadmap Project, funded by the composting industry along with Federal and State Governments, commenced to primarily develop the agricultural market for Compost. One of the preliminary findings by the consultants running the project has been that while there are a range of government policies, strategies and regulations in place to direct organic diversion from landfill, there are few if any in place to drive the marketing of Recycled Organic and principally compost products.

We LACK policy and regulation to drive marketing of compost and Recycled Organics!

There is also national interest in regulating the application of compost, however without clear policy acknowledging the importance of recycling organic wastes back to agricultural and other land uses, the risk is that they will focus on managing risks rather than promoting benefits and therefore restrict this potentially significant market.

Because of the benefits of soil organic matter, policy and regulations that assist the safe recycling of organic wastes will benefit and protect our soil and water resources, community health, agricultural performance and biosecurity.

Policy and regulation needs to:

- **Prioritise the safe recycling of organic waste to land; and**
- **Underpin the safe application of all organic materials to land.**

In Western Australia, the Minister for the Environment has initiated a working group to establish minimum standards for applying all organic materials and not just compost to land. This broad approach has been taken because manures, sludges and food waste all have significant potential to spread disease, pests and weeds and often contain high levels of heavy metals.

The uncontrolled distribution of 'raw' mulched plant material also contributes to the spread of diseases, pests and weeds and presents an unacceptable risk to commercial agriculture. It should also be unacceptable to the community because this practice posses a significant risk to biosecurity when unavoidable delays between a biosecurity incursion and its detection result in its significant spread, as was the recent case in California with Sudden Oak Decline.

Unregulated distribution of 'raw' mulched plant material possess a biosecurity risk.

The composting process provides a mechanism for managing all of the risks associated with recycling organics because it is amongst the best and most adaptable technologies for pasteurising organic materials (Millar 2002). Further as composting usually involves blending a range of feedstocks, dilution can also be used to manage contaminant levels.

To date the compost industry has been well served by the Australian Standard for Compost, Soil Conditioners and Mulches (AS-4454). They define minimum processing requirements for pasteurisation and provide a range of minimum test values for compost and related products. It also defines procedures and protocols for their measurement that allow reliable comparison between test results. Through reference to the standards for the application of 'Biosolids' to land and to relevant Health Regulations provided under the Health Act. Compliance with these standards will enable the recycled organics industry to demonstrate compliance with community health and natural resource protection requirements.

Compliance with minimum standards MUST NOT be interpreted as implying specific quality attributes and therefore a products suitability for specific use(s).

Regulation should ONLY be used to implement compliance with minimum standards that protect health and natural resource quality.
Quality above these minimum standards MUST be left to voluntary processes!

Further, care must be taken to ensure that compliance with a minimum standard are not used to support the universal use of a compost product. This is an unrealistic expectation given the wide range of attributes necessary to determine suitability for the almost infinite range of possible uses. This can be the case with the Australian Standard (AS-4454) because compliance tends to be used to imply suitability for all agricultural uses. This is not an appropriate use of these standards and these problems are in the authors view exacerbated because the focus of this standard is directed to the nursery and urban landscaping market use of potting mixes and soil conditioners. For this reason the Californian approach of compliance with minimum standards accompanied by a voluntary process of disclosure is preferred.

The use of standards or other regulatory devices to manage quality, over and above minimum health and resource quality protection, cannot be supported. The Californian Compost Quality Council investigated the establishment of minimum quality product standards without success (Paulin 2002 Report).

This was largely because of the difficulty in defining a limited number of product categories for which practical minimum standards could be described. Ultimately they resolved to leave compost quality management to industry.

The implementation of minimum standards for application of organic materials to land in Western Australia could be modelled on the Californian approach. They require licensed compost producers to demonstrate compliance with minimum standards, usually via independently audited Quality Management programs.

The Council had subsequently developed a voluntary process of disclosure. This requires participating members to provide customers with a minimum set of product specifications that can be used to assess a product’s suitability or ‘fitness for purpose’ for a given use.

They have also invested in education processes to better inform the market on how to select products for specific needs.

Carbon/greenhouse gas emissions and renewable energy credits are being implemented internationally for the production of energy from renewable resources that include organic wastes. They provide economic incentive to the renewable energy industry that predominantly, are not available to composting and preferred processes that will recycle organic wastes back to the land.

Carbon credits can be applied to the use of compost; however the accounting system is not well suited to most composting operations. Also they do not account for the range of additional environmental benefits associated with long term improvements to soil quality that can be attributed to compost use. A system of environmental credits is therefore needed to provide additional financial incentives to assist the beneficial recycling of organic wastes back to the land.

Cost is a major issue for recycling organic wastes and the situation will be exacerbated by the proposed implementation of minimum standards that will impose at least minimum processing requirements on recycling all organic materials.

This inequity needs to be challenged on the basis that recycling organic wastes provide greater benefits than energy recovery because when they are applied to the land:

- Some of the carbon will be retained as soil organic matter and will directly contribute to reducing atmospheric carbon dioxide levels; and
- Organic matter provides numerous benefits to soil quality, agricultural productivity and will contribute additional environmental benefit by improving the quality of both our water and air.

The major driver for the diversion of organic wastes from landfill has been its contributions to greenhouse emissions and groundwater contamination. Diverted organic materials are accumulating as diversion continues to increase, readily accessible urban markets for recycled organic wastes are becoming saturated and the slow agricultural market development continues. This is increasing the risk that significant quantities of organic wastes will be diverted to energy recovery and it needs to be accepted that once the necessary capital investments have been put in place, this process will not be easily reversed.

Source separation and issues for Mixed Waste Composting

Composting Municipal Solid Waste (MSW) is being increasingly considered as a means of achieving greater recovery from this waste stream that typically contains more than 70% by weight of compostable organic material.

Concerns include:

- Contaminant levels associated with metal, chemicals, biotoxins, possibly unknown substances and inert materials.
- Likelihood that capital investment required by MSW composting facilities will reduce further investment in source separation of organic wastes.
- Likelihood of greater disruption when a significant contaminant enters the waste stream. This has been illustrated by recent herbicide (clopyralid) contaminant in the United States and New Zealand. Because the lawn clipping source of this contaminant could not be readily removed, several MSW plants were closed down in the United States; and
- Potential environmental concerns associated with the impacts of the 'in vessel composting process on some relatively inert contaminants such as plastic film and polystyrene (H. Hoitink, personal communication).

MSW compost quality concerns based on US and European experience may not be relevant in Western Australia because of lower heavy metal levels and improved technology for dealing with contaminants such as glass.

Some of these concerns have been discussed in a report from the New York Environmental Institute, October 1991 'Garbage in / Garbage out? A hard look at Municipal Solid Waste Composting'. These concerns are increased by the history of MSW composting in the USA and Europe that has seen its importance significantly decline. In Western Australia however, it is argued that improved processing technology and better separation of urban from industrial wastes result in lower contaminant levels.

The debate on the merits of source separated waste stream composting also relate to its management. Blending feedstock allows flexibility in managing C:N ratio and the texture or porosity of the composting mass. This can have quality implications by allowing better process management. These considerations are particularly important in conventional windrow and static pile systems where either mechanical agitation or forced aeration is needed to manage the decomposition process.

Compost from source separated waste streams allows contaminant levels, such as heavy metals, to be adjusted by varying quantities of different feedstock.

Source separated organics also provide an opportunity to blend materials and to manage unacceptable contaminant levels that may be present in some feedstock's or components of waste streams.

Building linkages between agriculture and the community

A recent resolution by the Soil Science Society of America advocating global enhancement of soil organic matter highlights growing international recognition for the value of soil organic matter, and therefore the benefits of reusing organic waste in agriculture to manage and enhance soil organic matter. The resolution put up for international adoption, stated:

> "We resolve that organic matter is a resource that must be restored and increased globally to reduce the net rate of increase in greenhouse gases, to increase plant productivity and improve environmental quality". Global climate change, food security and environmental quality are interrelated issues of importance to all Nations and our Planet, and these can be favourably and simultaneously addressed by global enhancement of soil organic matter.

The significance of managing soils, and particularly the potential to use composted organic waste, is also being addressed by the European Union through development of a comprehensive policy to protect soil. EU-25, the Thematic Soil Strategy for 'Organic matter and compost quality in the future', brings together the findings of five interdisciplinary working groups. In summarising their work it emphasises the inherent link between soil quality and the use of composted exogenous organic matter.

Recognition of the strategic importance of agricultural land in the planning process resulted in the recent establishment of a Statement of Planning Policy for Productive Agricultural Land (SPP 2.5) in Western Australia. However despite this initiative, managing the continued urbanisation of rural (Peri urban) areas around the city has not been successful, largely because of the paradigm that favours urban development over the need to retain rural areas and associated agricultural activities.

Land use planning of rural areas needs to recognise the potentially important linkages that exist between rural and urban development. These linkages relate to:

- Agriculture's contribution to zero waste objectives through its potential to beneficially reuse the major, 50 to 60% organic component of the waste stream.
- Recognition that vegetable production and other irrigated horticultural activities are major potential users of reclaimed water. Justifying the capital investment for this to occur will probably require the establishment and retention of permanent agricultural zones or precincts, close to urban centres.
- Agriculture's reuse of organic waste will reduce the potential negative impacts of these industries on soil and groundwater quality. This outcome will be of immediate importance to the establishment of precincts for long term intensive horticultural production.
- Growing recognition for the potential for locally produced fresh food to contribute to reducing spiralling health cost. Fresh food quality and benefit is maximised and the energy costs associated with its production minimised when reliance on transport and storage is minimised; and
- Contribution to employment, tourism and agri-business opportunity and to the diversity of social and community values associated with rural landscapes in the peri urban environment. These values are already recognised in planning policy for the Swan Valley and are being developed in conjunction with the North Wanneroo 'Rural Way' process.

The current situation, and the failure to effectively address it, is common to urban development areas throughout Australia and most of the Western World.

Conclusions

Conclusions and recommendations are presented under the following headings:

- Market development
- Quality – including terminology and feedstock management
- Policy, Regulation and Standards
- Land use planning

Market development

The development of appropriate policy and regulation that is dealt with separately in a following section is arguably the most important component in the rapid development of the agricultural market for Recycled Organic Products. This aside, the immediate improvement to returns from using compost, information and production system changes that maximise the benefits of compost use will be needed.

Market development requires:
- **Policy and regulation.**
- **Improved returns.**
- **Information.**

Improving returns: In addition to policy and regulations, developing the agricultural market for compost will require a concerted effort to improve grower returns in the short term and to build confidence in its long term value through the development of improved production systems.

Key to this will be to increase their competitiveness with a range of existing organic 'waste' products including manures, biosolids and 'raw' shredded green waste. These products have few if any processing costs or as in the case of biosolids, are heavily subsidised. In addition to strategies discussed under policy and regulations, approaches include:

- Redirecting a proportion of current landfill levies to provide a rebate on the use of Recycled Organic Products, possibly within targeted market sectors. This approach would better drive the compost consumption than the current use of levy funds that tend to encourage processing without a well defined 'market development focus.
- Adjusting the balance of costs between waste producer and the product user. Reductions in compost cost need to be achieved through the application of 'extended producer responsibility' (EPR) principals that shift the balance of costs to the waste generators rather than by reducing the returns to the compost industry; and
- Increasing the landfill levy; the current level of the $3 per tonne of putrescible waste landfilled is insufficient to provide a real disincentive to landfill disposal. Increasing the landfill levy on putrescible wastes will increase 'gate fee' revenue to the Recycled organics Industry and will contribute to making products more competitive.

Improving returns:
- **Rebates on use.**
- **Application of EPR principals.**
- **Increasing landfill levy.**

It can be argued that current applications of the levy are providing disincentives and barriers to the continued development of the existing composting industry by encouraging the production of minimum cost and 'minimum' quality products. Whilst there are always going to be low grade products on the market, an increase in the landfill levy and use of levy funds to provide rebates on compost use will provide significant change.

Information and production systems: Market development will be assisted by products and information packages that enable growers to adjust their practices associated with compost use, with minimal disruption to tight and often complex cropping schedules. These products should also be capable of assisting on going improvement to their overall management practices.

They would include electronic packages that can adjust fertiliser and irrigation management to accommodate changing soil fertility and performance associated with compost use. The packages would address specific cropping situations, be able to interpret soil analysis results, adjust fertiliser and irrigation programs to match identified best nutrient management practice and incorporate capacity to quantify changes to costs and estimate changes to returns. Ultimately these packages could also assist with pesticide use and the development of integrated programs for managing disease, pests and weeds.

Growers, particularly in the intensively managed horticultural industries, are under increasing pressure to reduce potential adverse impacts of their management on soil and water resources. Assisting growers to build better overall management programs will be critically important to this. The development of better management systems will inevitably increase grower recognition for the importance of improving soil performance and consequently the importance of compost through its role in building soil organic matter levels.

Quality

Compost quality is complex and related to maturity.

Compost quality and hence maturity is related to its intended use and is a major consideration for market development. Measuring compost maturity is a complex issue and investigating the application of the Californian Compost Maturity Index under local conditions could also make an important contribution to agricultural compost market development. Quantifying compost maturity will enable better process control and should result in more consistent compost quality, allowing growers to more regularly achieve maximum benefit from its use.

Encourage voluntary disclosure of product quality within Industry marketing management programs.

A voluntary process of disclosure providing information that enables end users to make an informed choice between composted products (modelled on the Californian example) will also assist market development.

Terminology: The definition of compost and the terminology associated with compost quality needs to be clarified and widely promoted. It is suggested that any definition of compost includes reference to its stability (Figure 1) and that compost quality will be related to its level of maturation. Compost maturity reflects the level of further composting, once stability is achieved, and significantly influences its best use.

Feedstock management: The use of source separated feedstocks is likely to maximise quality, particularly in the more challenging markets such as vegetable production. This is because it maximises the potential for blending feedstocks to achieve required nutrient characteristics, microbial diversity and other aspects of compost quality.

If a contaminant enters the waste stream, source separation can also minimise disruption to compost production because its removal will be restricted to certain waste streams and therefore unlikely to shut down the entire composting process. Better resource recovery will also be possible because source separation reduces the potential for cross contamination of waste stream components.

MSW composting provides a mechanism for reusing a significant component of our waste streams that are currently being lost to landfill disposal. New technologies to manage physical contaminants will continue to emerge and support for MSW composting should continue providing:

- Efforts to increase source separation are not reduced.
- Minimum safety standards for protecting the soil and water resources as well as human and crop health are met; and
- They compete with conventional compost production on the basis of performance rather than cost.

Source separation of wastes can increase compost quality and enhance perceptions of the composting industry by:

- **Increasing process management options.**
- **Minimising nutrient/heavy metal content problems.**
- **Minimising potential disruption by more effectively excluding contaminants.**
- **Maximising resource recovery; and**
- **Increasing marketability of products.**

A challenge lies in ensuring that products of a lower grade are not seen as substitutes for higher grade products in a compost market that is still in its early stages of development. Therefore opportunity to create a market distinction that differentiates between products that meet the minimum requirements of AS4454-2003, need to be considered. This could involve embedding the 'disclosure' approach with an industry managed quality management 'Seal of Approval' program for which a number of models exist.

Contaminant management: In the interest of improving compost from both MSW and source separated feedstock, efforts should also be supported to remove contaminants from the organic waste stream that potentially reduce compost quality. In addition to household chemicals and other biologically toxic substances and chemicals, consideration also needs to be directed at other relatively inert contaminants and in particular, plastic films and bags.

Legislation to make the use of compostable plastic in the manufacture of shopping bags and possibly other products compulsory, will improve compost quality and have minimal cost effect to the community.

Replacing plastic 'shopping bags' with biodegradable bags made from 'compostable' Polycarbonate plastics derived from starch and cellulose rather than hydrocarbons from the petroleum industry would significantly improve the quality of most composts. The use of biodegradable plastic film/bags and potentially other plastic products will be more expensive. Their introduction therefore needs to be managed in conjunction with regulatory compliance rather than through voluntary process in order to ensure that additional costs are applied equally to all parties. This approach is likely to significantly benefit the composting of food wastes that invariably have high levels of plastic contamination.

Efforts are needed to minimise the potential for unexpected contaminants to disrupt all components of the Recycled Organics Industry. Recent issues, principally in the USA and New Zealand, with herbicide (clopyralid) highlight this potential risk. Approaches to registration authorities such as the National Pesticide Registration Authority are therefore needed to ensure that future pesticide and other chemical products are tested for their biodegradability within aerobic composting processes.

Policy, Regulations and Standards

The reality is that without appropriate policy and the consistent application of regulations, the development of agriculture as a market for compost, at least in the short to medium term, will be limited.

Organic waste management: Debate on the interpreting the 'Waste hierarchy' emphasises the need for policy to acknowledge the importance of soil organic matter conservation and the potential for organic wastes to contribute to soil organic matter management. This policy will underpin the waste hierarchy and the importance of recycling organic wastes over energy recovery from organic waste. It would not rule out energy recovery but would clearly direct it to handling components of the organic waste stream that cannot be processed by the Recycled Organics Industry.

Policy needs to clearly recognise the importance of soil organic matter and the potential for recycling organic wastes to contribute to its management.

Establishing this policy will also be in line with declarations by the American Society for Soil Science and the European Union directive EU-25 relating to soil protection. Both recognise the contribution that land application of organic wastes will make to the long term sustainability of agriculture, to society and to environmental health.

The reuse of organic wastes is a mechanism for building soil carbon that has significant benefit for developing more sustainable crop production as well as sustainable communities.

This policy approach is in general agreement with the Sustainability Guide and Industry Code of Practice developed by the Waste Management Association of Australia (WMAA) Energy from Waste Division.

A system of 'environmental credits is urgently needed to support the preferred strategy of recycling organic wastes to land.

Environmental credits: At present, the renewable energy and carbon credit processes support the development of the Renewable Energy Industry and the importance of this is acknowledged. However given the potential for energy recovery to compete with recycling of organic wastes and limitations for developing markets for recycled products, priority should be given to developing a parallel incentive system for recycling organic wastes that is at least the equivalent of renewable energy credits.

Regulating the Recycled Organics Industry: Imposing minimum quality standards for the application of all organic materials to the land will protect land and water resources, environmental and social values, and aid biosecurity. It will also provide a market that better allows compost and other recycled organic products to compete on the basis of performance rather than least cost as is currently the case with a range of organic materials.

Regulatory processes MUST not be used to manage compost quality. However, using regulations to impose minimum standards on the manufacture of composted products will make a significant contribution towards building market and community confidence in their use.

Licensing the Recycled Organics Industry and requiring demonstration that all products meet minimum standards for application of organic materials to land will facilitate orderly industry development and protect community, industry and environmental standards.

A model for implementing minimum standards for land application of organic materials could be the Californian approach that licenses compost producers and requires them to demonstrate compliance with a set of standards that protect health and natural resource quality.

Minimum standards are needed for the application of ALL recycled organic materials to land.

Processing more than 1000 tonnes per annum of organic wastes in Western Australia requires a licensed and compliance with proposed minimum standard could be made part of that licence and or the license renewal process. An important element of this would be to implement a compliance auditing process.

These minimum standards for all recycled organic products, including manures, liquids and sludges including biosolids, grease and food waste, as well as shredded/ground plant material, could be based largely on existing standards and regulations that apply to various materials and industry sectors. The proposed minimum standards would ensure that Recycled Organic Products:

- Are adequately pasteurised to manage disease, pest and weeds and address biosecurity concerns – AS 4454.
- Comply with heavy metal standards – the Californian standards developed by the US Department of Agriculture should be considered.
- Comply with or develop standards for chemical, biotoxins and other contaminants based on risk assessment based on the use of Hazard Critical Control Point (HCCP) analysis.
- Comply with human health standards – Health Act.
- Address Occupational Health and Safety concerns associated with contaminants such as glass and possibly plastics.
- Comply with other appropriate regulations such as fly breeding regulations under the Health Act.

This approach will underwrite orderly market development for Recycled Organic Products and allowing different products to compete on the basis of performance rather than lowest cost.

The introduction of these proposed uniform quality standards will increase costs associated with managing manure wastes from the intensive animal industries in particular. Acknowledging that most of these industries will have limited capacity to absorb these added costs, considerations will need to be given to managing their introduction and allowing them to adjust. Support mechanisms such as the proposed ‘Environmental credits’ would assist.

Consideration should also be given to allowing the reuse of organic wastes that are generated and reused on the same site without the application of the proposed minimum standards. The definition of same site would need to be accurately defined and the reapplication would need to be within the environmental receiving capacity of the site. This would assist industries such as Agro Forestry where current practice is to reuse harvesting wastes for the next on site tree crop.

Finally an important consideration in establishing minimum application levels will be to minimise requirements for management plans and to ensure that the compliant recycled organic products (compost) are subjected to exactly the same requirements as other agricultural inputs. In sensitive areas, they would be included when the preparation of nutrient and irrigation management plans is required.

> **In California, 'Product disclosure' provides information for determining the fitness of a product for a given purpose, enabling more informed product choice!**

Supporting compost/product quality: Acknowledging the considerations by the Californian Compost Quality Council outlined earlier, the development of quality standards to aid 'best use' determination for recycled organic products, will be best managed by the composting industry. These could include the use of the Californian 'minimum disclosure' approach in which participants agree to provide a minimum level of product information to their customers.

> **Quality MUST not be regulated.**

Industry organisations such as the recently established Recycled Organics Western Australia (ROWA) group, a sub group of the Waste Management Association of Australia, could play a significant role in developing this process and could possibly develop 'Fit for purpose' compost specifications that could underpin the development of a minimum disclosure process.

These fit for purpose specifications could also be incorporated into the Australian Standards, AS 4454.

Approval process for Recycled Organic Businesses establishment: There is a need to reduce the time and costs associated with establishing a Recycled Organics Business. Difficulties are associated with significant up front capital investment, annual licence renewal, and general community resistance based on the 'Not in my back yard' approach. Costs and delays are exacerbated by elements of the process being managed by the Department of Environment and the Department of Planning. The approval process will be assisted by:

- Deferring capital requirements that generally involve establishment of extensive hard stands and capacity to store run off from a 100 year rainfall events, and making them a requirements of future licence renewal.
- Extending the license renewal cycles based on the level of capital investment involved and the need to recover those costs.
- Manage community resistance by facilitating early communication between neighbouring land holders, community groups, government and the proponent.
- Coordinating the requirements of planning and environmental licensing processes.

Land use planning

Land use planning policy needs to be further strengthened to manage the continued urbanisation of rural areas and the associated productive agricultural land.

There is also growing recognition of the strategic importance of rural land and the associated activities to urban communities. A key element of this includes recognition is that vegetable production as well as other intensive horticultural industries are ideally located to utilise both organic wastes and reclaimed water from urban development.

Further opportunity to strengthening the implementation of the Statement of Planning Policy (SPP 2.5) for 'Productive Agricultural Land' to protect productive agricultural land should also arise from promoting recognition of their importance in:

- Providing local fresh food - imported food can not adequately meet requirements for food quality, safety and security of supply.

- Underpinning rural economy, better managing soil and water quality through the use of composted wastes; and facilitating the retention of environmental, ecological and social diversity associated with rural landscapes; and
- Servicing urban community by providing additional employment, business opportunity including tourism, and greater social diversity, in addition to managing their wastes.

The problems with the current failure to prevent this include:

- The use of compost and associated changes to management practices represent a relatively long term investment for farmers. The transitory nature of intensive horticultural industries that are strategically located to utilise compost and reclaimed water generated by urban populations is therefore a significant disincentive.
- The availability of land that has the same combination of resources (soil, water and climate) becomes increasingly limited. This reduces both the range of crops that can be grown and the season in which they can be produced, further restricting options for maintaining economic viability.
- The costs of organic recycling increases because of greater transport costs and in the case of the reuse of reclaimed water for irrigated crop production, significant costs for relocating infrastructure.
- Reduced opportunity for increasing proportions of urban communities to interact with rural community values and services; and
- Continued decline in the extent and range of natural ecosystems that will be better supported when there are viable agricultural and associated rural based industries available to support local rural economies.

The dominance of urban planning over rural is driven by short term economic considerations that benefit the property development industry; as well as rural landholders who are provided with a capital return that either funds retirement or expansion. It does not consider triple bottom line considerations that reflect the wider values associated with the above listed.

Because under the present situation, land values in rural areas reflect their potential for urbanisation, expansion by purchasing neighbouring property is not viable in most situations. Consequently, expansion has to be accomplished by selling out to urban development and moving further ahead of the advancing urban boundary to purchase and develop larger properties. Around the metropolitan Perth boundary, this cycle has been repeating every 10 to 15 years.

Recommendations

Recommendations presented include comment on any current progress and key steps needed. They are the views of the author and are intended to provide some guidance to possible policy development that will better aid the recycling of organic wastes.

1. Market development

Investigate ways to improve grower returns from using compost.

RECOMMENDATION 1.1 – Utilise some of the land fill levy funds to provide a rebate incentive for compost use in prescribed/approved situations.

Landfill levies could in part be redirected to provide a rebate for a period of time in selected compost markets.

RECOMMENDATION 1.2 – Reduce the final cost of composted products in the market place by:

- Increasing landfill levy on putrescible wastes and hence the related costs of alternative disposal to the organic recycling industry.
- Increasing contributions from generators of organic wastes relative to ‘cost recovery’ required by the Organic recycling industry.

This recommendation reflects the principals of ‘Product Stewardship’, ‘User Pay’s and EPR – ‘Extended Producer Responsibility’.

RECOMMENDATION 1.3 – Develop information and electronic management packages that enable growers to adjust their practices to utilise compost with minimal disruption to their management.

Recommendations to directly influence agricultural use of compost include:

The development of packages to facilitate grower use of compost could be funded by stakeholders and is likely to be identified in the outcomes of the current ‘Compost Roadmap Process’.

RECOMMENDATION 1.4 – At a national level, develop improved production systems that focus on managing soil carbon (Soil Organic Matter) and the development of ‘best practice, ‘Triple Bottom Line’ sustainability for industries identified as key markets for recycled organic products.

This acknowledges the need to satisfy growing global requirements for ‘clean, green and safe food production, and their potential to contribute to sustainable organic waste recycling.

This recommendation has been put forward for consideration by the Roadmap Project and would include the development of management packages, Recommendation 1.4.

2. Quality

The development of the compost market will be assisted by the development of reliable measures for compost quality/maturity.

RECOMMENDATION 2.1 – Support the development of cost-effective compost maturity standards that are appropriate to local and national conditions.

The development of a cost-effective compost maturity index could be included within research and development outcomes from the current ‘Compost Roadmap Process’.

Suggested changes to selected definitions in the ROU Recycled Organics Dictionary are provided in the appendices to this discussion paper.

RECOMMENDATION 2.2 – Develop an agreed consistent terminology to describe compost production and quality as outlined in Figure 1.

Recommendations to this effect, developed through the Compost Roadmap process, rather than submitted by individual state registration committees and groups, could simplify the process of getting this dealt with as a national imperative.

RECOMMENDATION 2.3 – Influence National Pesticide Registration processes to ensure that all new chemicals are tested for their biodegradability within aerobic composting processes.

Recent herbicide (clopyralid) contamination highlights the potential for chemicals to significantly disrupt compost production and marketing.

Recommendations to this effect, developed through the Compost Roadmap process, rather than submitted by individual state registration committees and groups, could simplify the process of getting this dealt with as a national imperative.

RECOMMENDATION 2.4 – Provide policy and resources to support the collection of source separated organic wastes and the removal of contaminants that impact on compost quality.

3. Policy and regulation

The strategic importance of the potential value of reusing organics to manage soil organic matter warrants support by appropriate policy.

RECOMMENDATION 3.1 – Promote policy that:

- States the importance of Soil Organic Matter and the potential role of recycled organics in its management and conservation.
- Prioritises safe recycling of organic wastes through their land application and principally to agriculture;
- Supports recycling organic wastes above energy recovery.

ROWA could seek support of the Department of Agriculture in promoting the development of policy for the protection and enhancement of soil organic matter within the Environmental Protection Act.

RECOMMENDATION 3.2 – Develop 'Minimum Standards' for land application of all organic materials that manage:

- disease, pest and weed contaminants, including associated biosecurity risks, as set out in AS 4454;
- health concerns in line with Public Health requirements, including fly breeding;
- contaminant levels that include heavy metals/nutrients, chemicals and biotoxins, and when there are Occupational Health and Safety concerns, inert materials.

Note: *Consideration MUST be given to exempting organic wastes that are generated and that can be safely reused on site*.

Implement regulation and appropriate compliance to implement minimum standards for the safe application of ALL organic materials to land.

Minimising the associated cost and restrictions on the development of organic recycling industry needs careful consideration and management. The application of the HACCP approach should help to ensure that sectors of the industry are not unfairly burdened.

The Organics Standards Working Group is currently addressing the need to create uniform conditions for the land application of all organic materials on behalf of the Waste Management Board and the Minister for the Environment and Science.

RECOMMENDATION 3.3 – Promote planning approval process for Recycled Organic Industry development that supports process development sites by:

- facilitating up-front community consultation between all stakeholders, including community, government and industry and to minimise planning delays when rezoning processes are involved;
- using license renewal process to defer the implementation of significant capital requirements including hard stands and leachate storage over a period of several years;
- extending the license renewal process significantly beyond the current annual requirement.

Coordinating the requirements of the approval process for Recycled Organic processing facilities could be undertaken by ROWA/WMAA.

RECOMMENDATION 3.4 – Support and encourage the development of compost quality management and processes such as disclosure of appropriate information for determining best use of a product.

Promote compost quality through voluntary programs rather than by regulation.

Voluntary disclosure of information to allow 'best use' of a product to be more readily determined could be supported with disclosure guidelines for major compost product categories within AS 4454.

RECOMMENDATION 3.5 – Promote provision of 'Carbon Credits' and or 'Environmental credits' for appropriate recycling of organic wastes through the Department of Premier and Cabinets 'Geenhouse Unit'.

4. Land use planning

Support and strengthen the Statement of Planning Policy (SPP 2.5) for the 'Strategic importance of productive agricultural land' because of its importance for:

- Managing waste that includes waste (reclaimed) water reuse.
- Management of soil and water quality, and environmental values.
- Servicing urban community through greater employment, business opportunity including tourism and greater social diversity.
- Production of locally produced fresh, safe food that will have maximum benefit to community health.

RECOMMENDATION 4.1 – Promote development of rural 'zoning' policy that allows land values to reflect their use for rural/agricultural purpose rather than potential urban values.

The strategic importance of retaining productive agricultural land should be promoted to the community, to the Department of Planning and Infrastructure, and to the Departments of the Environment and Agriculture by the Waste Management Board.

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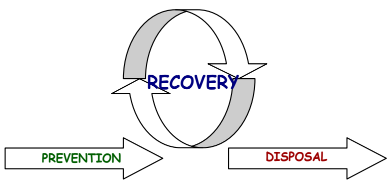

Disclaimer

The views, directions and comments contained in this discussion paper are those of the author and must not be taken to represent position or policy of the WA Government, the WA Department of Agriculture, the Waste Management Association of Australia or other industry organisations

Appendix 1. Composting terminology

Subject	Current description	Proposed description	Critical comments
Composting	The process whereby organic materials are pasteurised and microbially transformed under aerobic and Thermophilic conditions for a period not less than 6 weeks.	The process whereby organic materials are microbially transformed under aerobic and thermophilic conditions. Moisture, oxygen and temperature levels need to be managed within acceptable boundaries and by various mechanical processes and techniques that will determine when the required level of transformation is achieved. The transformation sequence being 'pasteurisation, stabilisation (= to immature compost) to increasingly mature compost. Providing pasteurisation is achieved, disease, pests and weeds will have been controlled.	Composting is PROCESS, it is **NOT** time bound! By definition, it is a process that must be carried out under controlled conditions yielding mature products that do not contain any weed seeds, pathogens or pests.
Maturation	Final stage of composting where temperatures remain steady below 45°C and the compost becomes safe to use with plants due to the absence of toxins. Synonyms: curing; stabilisation.	The second mesophilic stage of composting that follows the completion of the initial primary decomposition (thermophilic) phase and the achievement of stability. The level of maturation determines compost quality in terms of its 'fitness for purpose'. Managing adequate moisture and aeration continues to be necessary, and temperatures gradually decline.	Inadequate management of the maturation phase is frequently a cause of poor compost performance. Maturation is NOT SYNONYMOUS with curing; stabilisation!
Maturity (of compost)	Is related to the level of composting (that?) feedstock material receives. A mature product is stable and does not cause toxicity to plants. See also maturation and stability.	Relates to the level of second stage (mesophilic) composting. The level of maturity determines compost quality in relation to its best use.	Compost is a Stable product – its maturity ranges from immature compost that is still capable of impairing plant growth to very mature when the compost takes on soil like properties and is less useful in terms of increased plant performance.
Stability (of compost)	The rate of change or decomposition of compost. Usually stability refers to a lack of change or resistance to change. Stable compost continues to decompose at a very slow rate and has a low oxygen demand. See also maturation.	The stability of compost is a requirement for a composted product to be termed 'compost'. It is achieved once the primary thermophilic phase of composting is complete.	Stability like maturity is not easily defined. However, there are recognised measures of compost stability and screening of wood based composts is important in its determination.

Appendix 2. Product terminology

Topic	Current description	Proposed description	Critical comments
Compost	An organic product that has undergone controlled aerobic and thermophilic biological transformation to achieve pasteurisation and a specific level of maturity. Compost is suitable for use as a soil conditioner or mulch and can improve soil structure, water retention, aeration, erosion control and other soil properties.	A **STABLE 'safe to use'** source of organic matter that has undergone controlled aerobic and thermophilic biological decomposition and has achieved a specific level of maturity. Compost by definition has been pasteurised and is suitable for either soil incorporation or use as mulch. It provides a source of plant available nutrients, contributes to soil health and performance by stimulating beneficial biological activity, improving soil structure, cation exchange, water retention, aeration, erosion control and other soil properties.	Emphasis needs to be placed on compost being a stable *(see definition of compost stability)* product which implies that it can be safely stored without regressing to a 'putrefied state reminiscent of some or all of its feedstock's. Compost is more than a soil conditioner – we need to distance compost from the term 'soil conditioner'. A lot of products are soil conditioners.
Composted fine mulch	Any pasteurised product which has undergone composting for a period not less than 6 weeks excluding polymers which do not degrade (such as plastic, etc.) that is suitable for placing on soil surfaces. Composting fine mulch has not more than 15% by mass of particles with maximum size above 15 mm.	DELETE	DELETE, distinguishing between fine and coarse mulches is not warranted or particularly useful!
Composted mulch	Any pasteurised product which has undergone composting for a period not less than 6 weeks excluding polymers which do not degrade (such as plastic, etc.) that is suitable for placing on soil surfaces. Compost Mulch has at least 70% by mass of its particles with maximum size above 15 mm.	A stable composted product that is suitable for placing on soil surfaces. Composted Mulch has at least 70% by mass of its particles with maximum size above 16 mm.	Composting is process, not time bound.
Composted soil conditioner	Any composted product including vermicast, manure and mushroom substrate that is suitable for adding to soil. This term includes 'soil amendment', 'soil additive', 'soil improver' and similar terms but excludes polymers which do not biodegrade such as plastics, rubber and coatings. Soil conditioner has not more than 20% by mass of particles with a maximum size above 16 mm.		DELETE? Question need for this product definition – see Soil Conditioner below.

Appendix 2 continued …

Topic	Current description	Proposed description	Critical comments
Pasteurised fine mulch	Any pasteurised product (excluding polymers such as plastic, etc.) that is suitable for placing on soil surfaces. Pasteurised fine mulch has not more than 15% by mass of particles with maximum size above 15 mm.	A pasteurised organic product that is suitable for placing on soil surfaces. Pasteurised fine mulch has not more than 15% by mass of particles with maximum size above 15 mm.	DELETE, see comment for fine composted mulch!
Pasteurised mulch	Any pasteurised product excluding polymers (such as plastic, etc.) that is suitable for placing on soil surfaces. Mulch has at least 70% by mass of its particles with maximum size of greater than 15 mm.	A pasteurised organic that is suitable for placing on soil surfaces. Mulch has at least 70% by mass of its particles with maximum size of greater than 15 mm.	**ONLY MULCH term warranted!**
Pasteurised product	A process whereby organic products are treated to kill animal and plant pathogens *(pests?)* and plant propogules. Pasteurisation can be achieved by the controlled biological transformation of organic materials under aerobic and thermophilic conditions such that the whole mass of constantly moist material is subject to at least 3 consecutive days to a minimum temperature of 55^{o}C (or by equivalent process).	A product that has been subjected to temperatures and moisture levels over a specified continuous period to control animal and plant pathogens, pests and plant propogules. Pasteurisation can be achieved with the composting process when the whole mass of organic materials are subjected to constantly moist aerobic and thermophilic conditions for at least 3 consecutive days at a minimum temperature of 55^{o}C (or by equivalent process).	A pasteurised product is one that has been subjected to the pasteurisation process.
Soil conditioner	Any composted or pasteurised organic material that is suitable for adding to soil. The term also includes ‘soil amendment’, ‘soil additive’, ‘soil improver’ and similar terms but excludes polymers which do not biodegrade such as plastics, rubber and coatings. Soil conditioners may be either ‘composted soil conditioners’ or ‘pasteurised soil conditioners’. Soil conditioner has not more than 15% *(WHY NOT 20% as with composted soil conditioners)* by mass of particles with a maximum size above 15 mm.	Soil conditioning products need to have been pasteurised and when they contain organic materials, they need to be composted to achieve pasteurisation and a level of maturation that is determined by their end use.	NOTE earlier comments regarding distinction between Compost and the term soil conditioner - Appendix 2. Further, soil conditioners are not necessarily organic in origin. They should not be confused with compost!

Appendix 2 continued …

Topic	Current description	Proposed description	Critical comments
Manufactured soil		Manufactured soils include low-density soils, organic amended soils, top dressing and top soil. Products vary in their proportion of recycled organic material and include soil conditioners that also includes the terms ‘soil amendment’, ‘soil additive’, ‘soil improver’ and similar.	Need to comply with minimum standards as set down within the Australian Standards, AS 3743 – for ‘Potting mixes’.
Potting mix		A growing medium suitable for the establishment and development of a wide range of plants in containers.	Need to comply with minimum standards as set down within the Australian Standards, AS 4454 – 2003 for ‘Composts, soil conditioners and mulches’.
Playground surfacing		Material of a particulate nature (e.g. mulch), installed to a specific depth, absorbing the energy of an impact through its displacement. Loose fill materials are used for surfacing in children’s playgrounds to minimise the severity of head injury resulting from a fall from play equipment to the ground below.	Need to comply with minimum standards as set down within the Australian Standards, AS 4454 – 2003 for ‘Composts, soil conditioners and mulches’.

Appendix 3. Feedstock terminology

Product	Current description (comments)	Proposed description	Critical comments
Biosolids	Organic solids or semi-solids produced by municipal sewage treatment processes. Solids become biosolids when they come out of an anaerobic digester or other treatment process and can be beneficially used. Until such solids are suitable for beneficial use they are defined as waste water solids. The solid content in biosolids should be equal to or greater than 0.5% weight by volume (w/v). Biosolids are commonly co-composted with Green (Garden) Organics and/or residual wood and timber to produce a range of recycled organic products.	Include within sludges and liquid waste category, see below.	There is no *logical* reason to separately consider biosolids as is the current situation. It is important to move away from the stigma attached to biosolids as 'human sewage'. They need to be considered as one of the categories of compostable organic resources, providing requirements for the protection of community health and soil and water resources are met!
Food organics	Food organics are solid wastes from non farm based production and processing of crop and livestock products that include: fruit and vegetable material; meat and poultry; fats and oils; seafood (including shellfish), bread, pastries and flours (including rice and corn flours) food soiled paper products (paper towels, butter wrap, etc.). They include potentially recalcitrant or slow to decompose materials such as large bones > 15 mm diameter, oyster shell, coconut shells, etc.).		Bones are not particularly recalcitrant. The need for this type of comment is questioned. Materials such as rice hulls that are high in Silicon **are recalcitrant** with respect to aerobic decomposition!

Appendix 3 continued …

Product	Current description (comments)	Proposed description	Critical comments
Garden organics	The Garden Organics material definition is defined by its component materials including: putrescible garden organics (grass clippings); non woody garden organics; woody garden organics; trees and limbs; stumps and rootballs. Such materials may be derived from domestic, commercial and industrial and commercial and industrial demolition sources. Garden organics is one of the primary components of the compostable organic stream. Garden organics is the standard material description from the Australian Waste Database.	Identical definition with 'Green' replacing 'Garden'. The Green Organics material definition is defined by its component materials including: putrescible garden organics (grass clippings); • non woody garden organics; • woody garden organics; • trees and limbs; • stumps and rootballs. Such materials may be derived from domestic, commercial and industrial and commercial and industrial demolition sources. Green organics is one of the primary components of the compostable organic stream.	Replace Garden with GREEN. The term 'Garden' is **not universally** understood or interpreted terminology. It reflects an emphasis on urban and community organic waste management. Considerations need to be inclusive of all sectors.
Sludges, liquid and watery wastes	Semi liquid waste produced as a by-product of an industrial process.	Semi liquid waste produced as a by-product of an industrial process. They include **biosolids**, grease trap, liquid food and dairy wastes.	Providing the requirements for 'safe land application are met, biosolids and other sludges are potentially valuable composting feedstock. They are all basically anaerobic and this is not a barrier to their use in composting.

Appendix 3 continued …

Product	Current description (comments)	Proposed description	Critical comments
Woody garden organics	Refers to all compostable plant material that has a diameter between 5 and 150 mm that are appropriate for collection and use as feedstock materials for composting in related biological treatment systems. Such materials may be derived from domestic, commercial and industrial and commercial and industrial demolition sources. These materials contain a significant wood or cellulose component, requiring different size reduction technology from non-woody Garden Organics. Examples include: branches, twigs and bark. Woody Garden Organics forms one of the material description sub-categories within the Garden Organics material description from the Australian Waste Date Base – *Appendix D, Recycled Organics Dictionary and Thesaurus.*	Refers to all compostable plant material that contains significant wood or cellulose component, requiring different size reduction technology from non-woody Green Organics. Such materials may be derived from domestic, commercial and industrial and commercial and industrial demolition sources. Woody Green Organics forms one of the material description sub-categories within the Green Organics material description from the Australian Waste Date Base – *Appendix D, Recycled Organics Dictionary and Thesaurus.*	Replace ‘Garden’ with ‘Green’ in the title and text. As previously discussed, the term ‘Garden’ is **not universally** understood or interpreted terminology.
Others		Paper, cardboard and other biodegradable products, (cutlery, bags, polymers).	

Appendix 4. Market terminology

Market	Current description	Proposed description	Critical comments
Horticulture - annual		Refers to the market segment within the recycled organics sector comprising commercial annual crop production including vegetables, strawberries, cut flowers, and nurseries.	
Horticulture - perennial		Refers to the market segment within the recycled organics sector comprising commercial perennial crop production including: orchard and vineyard crops – apples, pears, stone fruit, grapes – wine, table and drying, citrus, olives, avocado and other tropical and sub tropical tree crops; nuts, turf grass growing, exotic and native flowers and foliage.	
Agriculture		Refers to the market segment within the recycled organics sector which incorporates: pasture farming; broad acre farming; forestry farming and landcare.	
Urban amenity		Refers to the market segment within the recycled organics market sector which incorporates: landscape; local government; nurseries – retail; special projects; state government; sport; and recreation and leisure.	
Rehabilitation		Refers to the market segment within the recycled organics market sector which incorporates: landfill cover and rehabilitation, erosion control, revegetation and environmental restoration (landcare).	
Enviro/bio-remediation		Refers to the market segment within the recycled organics market sector which incorporates: contaminated sites and soils; stormwater purification; and air filtration (odour management).	

Source: [1] Recycled Organics Unit (2003). Recycled Organics Dictionary and Thesaurus. http://www.rolibrary.com.
[2] WA Recycled Organics Working Group.
[3] NSW Agriculture – comments on proposed national compost survey.

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