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Compost SFF Final Report (2009–12)

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A report prepared for

SFF Project 09/152:
Sustainable use of municipal compost for the
agricultural sector

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This report has been prepared by The New Zealand Institute for Plant & Food Research Limited (Plant & Food Research), which has its Head Office at 120 Mt Albert Rd, Mt Albert, Auckland.

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Executive summary

- The impact of municipal compost in pasture, forage crop, intensive vegetable and arable crop rotations was tested in field trials in South and mid-Canterbury. These trials assessed the effect of compost on yield, soil health indicators and financial viability.

- Results indicated that mature municipal compost can enhance crop production for at least 2 years following a single application in arable, pastoral and forage cropping systems.

- The most profitable scenario in a 3-year arable rotation was 3 annual applications of 8 t/ha compost applied with a one third reduction in recommended N fertiliser.

- The second most profitable scenario in the arable rotation was a one-off application of 50 t/ha compost with no offset to N fertiliser.

- In a forage rotation, one-off applications of 25, 50 and 100 t/ha of compost with no fertiliser N offsets over two consecutive kale crops resulted in cumulative yield increases of 12, 31 and 45% respectively, with the 50 t/ha rate being the most profitable.

- In a forage brassica rotation, compost application rates of 12 t/ha with a 40% reduction in fertiliser N increased yields by 18%. This 1-year scenario was financially viable for freight costs up to $14/t.

- If applying 8–12 t/ha compost, applications should be made regularly (every 1–2 years). Small regular applications are the most financially viable.

- If applying 25–50 t/ha compost, reapplications should be made every 3–4 years. Over a 3-year cropping rotation 50 t/ha is more financially viable then 25 t/ha.

- Particulate organic matter (a short-term reservoir for plant nutrients) and available N were still elevated where compost had been applied at the end of both the arable and forage crop trials. This suggests that benefits beyond the scope of these trials are likely.

- Soil organic matter and carbon content increased significantly where compost was applied.

- Even though soil organic matter performs a number of important functions in soil such as minimising compaction pressure, soil physical parameters such as bulk density remained largely unaffected by one-off compost applications over the timescale of these trials.

- With high rates of compost, there was a trend towards improved soil structural stability and water holding capacity, suggesting further improvements with time and sustained applications are likely.

- Complete substitution of fertiliser with compost is not recommended; to get the best out of compost it needs to be applied with fertiliser N.

- A crop's ability to respond to available N (from soil, fertiliser and compost reserves) increases where compost has been applied. The mechanisms that underpin this observation are not well understood and require further research to elucidate the key processes and critical factors.

- Other important crop nutrients besides N (such as P, K, Mg and Ca) are provided by compost, with compost additions resulting in greater availability of these nutrients for crop uptake over prolonged durations.

- Soils that have been cropped for a number of years or that are inherently low in nutrients such as P and K may especially benefit from using compost.

- Due to much of the N content in compost being in a slow release organic form the amount of nitrate leached did not increase when compost was applied. There may be potential to reduce total N leached where compost applications offset fertiliser rates.

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1   Introduction

When these field trials began, about 726,000 t of municipal garden and kitchen wastes was being buried in New Zealand landfills annually. A recently set Ministry for the Environment (MfE) target is to reduce the quantity of waste (tonnes) disposed to landfill per person per year by 20 per cent relative to an established 2010 baseline. Composting can help meet this target by lowering the volumes of landfill wastes while creating a resource rich in nutrients and organic matter. Although farmers are enthusiastic about using compost, there is little information and no established guidelines to support its sustainable use in New Zealand agricultural systems.

In 2007 Plant & Food Research was commissioned to undertake two on-farm trials to assess the effects of compost on the establishment and growth of forage kale and ryegrass, and the associated soil quality changes under each crop. The two trials were established at Karina Downs, South Canterbury, to run for 3 consecutive years (2007–10), with funding provided by Transpacific Industries, Canterbury Waste Joint Committee and Environment Canterbury.

Initial results from this research showed that compost can have significant short-term soil quality and fertility benefits that increase pasture and forage crop production. Therefore, additional funding was sourced through the MAF Sustainable Farming Fund in 2009 to extend the two existing trials at Karina Downs to June 2012, as well as provide the opportunity for additional field trials and lab experiments to establish guidelines for the sustainable use of compost on farm and to transfer the findings to farmers and other end users. The objectives of the project were to answer the following questions:

- Can one-off applications of compost result in measurable improvements to soil physical parameters such as water use efficiency and soil C storage through increases in soil organic matter?

- To what extent can compost applications reduce the need for mineral N fertilisers without compromising crop yields?

- How long before farmers should consider reapplying compost to the farm?

- What are the implications of using compost on farms in terms of nitrate leaching and possible ground water contamination?

- How will the recommended use of compost differ depending on agricultural sector, i.e. forage cropping v. arable cropping v. intensive vegetable production?

Further to the initial two trials in South Canterbury, a large-scale arable crop rotation trial was established at Lincoln in 2009; a dairy cow winter grazing forage crop demonstration site established on an ex-forestry property at Bankside in 2009; and an intensive vegetable production trial established in late 2010 in Marshlands, Christchurch. In addition to these field trials, an extensive incubation study was carried out during 2010–11 to obtain more detailed information about N release from compost under a range of temperature and moisture regimes.

This project was funded by the MAF Sustainable Farming Fund (project 09/152), Transpacific Industries Ltd, Canterbury Waste Joint Committee, Environment Canterbury, Ballance Agri-Nutrients, Foundation for Arable Research and Plant & Food Research; with additional in-kind input from Living Earth, Timaru District Council, Ministry for the Environment, Poulfert Ltd and the farmers/growers hosting the field trials.

The SFF project brought together the experience of representatives from the farming community, councils, composting industry and research providers to develop guidelines that will help to ensure the economic and environmentally sustainable use of compost in the primary sector. The findings will have national implications as large-scale production of municipal compost by local governments is

expanding across New Zealand to reduce loading to landfills by converting organic wastes (excluding biosolids) into quality compost products.

This final report contains additional data from 2011–12 as well as an overview of the field trials and incubation study that were carried out over the last 5 years.

2 Methods, experimental design and management

Numerous soil parameters were measured throughout the duration of each trial, and assessments of plant yield were made at the completion of each crop, immediately prior to grazing or harvest. All measurements were completed using standard analytical methods, as outlined below. Standard replicated practices were used to collect samples representative of the plots being sampled.

2.1 Compost analytical methods

The nutrient composition of compost applied at the field trials was carried out by Hill Laboratories Ltd, Hamilton, as outlined in Table 1.

Table 1: Procedures followed by Hill Laboratories in the chemical fertility analysis of compost.

Test Method	Description (Total recoverable nutrients reported on a dry weight basis)
Media & compost prep	Oven dried at 105°C for 24 hours and ground to pass through a 2 mm screen
Total sulphur	Nitric/hydrochloric digestion (based on US EPA 200.2) followed by ICP-OES
Total carbon, total nitrogen, organic matter	Sample dried and ground and analysed by Dumas combustion. Organic Matter is 1.72 x total carbon
Total phosphorus, potassium, calcium, magnesium, sodium, iron, manganese, zinc, copper, boron	Nitric/hydrochloric digestion (based on US EPA 200.2) followed by ICP-OES
Total chromium, arsenic, lead, nickel, mercury, cadmium	Nitric/hydrochloric digestion (based on US EPA 200.2) followed by ICP-MS

2.2 Plant analytical methods

2.2.1 Dry matter yields

Dry matter was determined by removing crop from representative areas of known dimensions from each plot. The dry matter was determined from the total fresh weight of plants and the moisture content of a representative sub-sample, dried at 60°C.

2.2.2 Plant organic C and total N

Organic C and total N was measured on representative plant sub-samples that had been oven-dried at 60°C. Organic C and total N was determined by an automated dry combustion (or Dumas) method using a LECO TruSpec CN analyser operating at 950°C.

2.2.3 Thousand seed weight

One thousand seeds (for peas, wheat and barley), counted using a Numigral electronic seed counter, were weighed and adjusted to 14% moisture content after having their moisture content determined by a Dickey-John GAC500XT capacitance moisture meter.

2.2.4   Marketable yield of fresh vegetables

The standard by which lettuces and cabbages were determined as being marketable was based on a combination of a visual assessment and weight. In general, plants which were misshapen or diseased, or with hearts under approx. 400 (lettuces) or 2000 g (cabbages) were classed as non-marketable.

2.3   Soil analytical methods

2.3.1   Soil bulk density

The fine-earth bulk density (<4 mm) was calculated from the weight of the field-moist soil taken from a known soil volume and corrected for its stone and moisture contents.

2.3.2   Moisture content at field capacity

Soil water content at field capacity (FC) provides a measure of a soil's capacity to store and supply water to a crop. Measurements of FC were made by inserting lysimeters into the soil, applying sufficient water over a period of approximately 30 minutes to saturate the soil, and leaving it to drain naturally for 24 hours before collecting a smaller soil core from the 0–7.5 cm depth of each lysimeter. These samples were then oven dried at 105°C to determine their moisture contents.

2.3.3   Drained upper limit

An undisturbed core was collected by cutting a column of soil whilst gently pressing a ring over the column; a carving technique that avoids shattering the core. In the laboratory, worms were removed from the cores using a heat treatment to bring worms to the core surface where they were removed by hand. Drained upper limit is a measure of a soil's field capacity, and was measured on tension tables at -10 kPa.

2.3.4   Earthworm populations

Earthworm populations were assessed at one position in each plot by careful sorting of the soil from a 36 x 18 cm hole to a depth of 20 cm. Earthworm populations are presented as no./m^2.

2.3.5   Aggregate stability

Aggregates 2–4 mm in diameter were separated by dry sieving and then air-dried at 25°C for aggregate stability determination using a wet-sieving method (Kemper & Rosenau 1986). The air-dried 2−4 mm aggregates (50 g) were sieved underwater for 20 min on a nest of sieves (2.0, 1.0 and 0.5 mm diameter openings). The soil remaining on each sieve was weighed after oven drying at 105°C. The aggregate stability was expressed as a mean weight diameter (MWD):

$$MWD = \sum_{i=1}^{n} x_i w_i$$

where x_i is the mean diameter of adjacent sieves and w_i is the proportion of the total sample retained on a sieve.

2.3.6   Structural condition score

The soil structural condition score (SCS) is a semi-quantitative assessment of soil structure that is obtained by examining the size, shape and porosity of the aggregates, their cohesion, and the root development in and around them, using samples collected from 0–10 cm depth. Assessments of SCS are made using a score card that combines photographs with descriptions of these soil structural features. Structural condition scores range from 1 to 10, where a high score relates to a well

structured soil and a low score to a poorly structured soil. Previous research has shown that crop yields tend to increase as the soil structural condition increases (Beare & Tregurtha 2004).

2.3.7 Soil organic C and total N

A sub-sample of soil for organic C and total N analysis was mixed thoroughly, sieved <2 mm diameter and oven-dried overnight at 60˚C. Organic C and total N was determined on single 0.4 g soil samples by an automated dry combustion (or Dumas) method using a TruSpec CN analyser operating at 950ºC.

2.3.8 Particulate organic matter

Particulate organic matter (POM) was measured as organic matter 250–53 µm in diameter. Briefly, 20 g of moist soil was dispersed in sodium hexametaphosphate (Calgon) solution by shaking overnight. The soil suspension was then washed through a stack of sieves with screen sizes of 1000, 250 and 53 µm. The material retained on the 250 and 53 µm sieves was dried at 60°C overnight, weighed, ground and analysed for total C and N on a LECO TruSpec analyser.

2.3.9 Soil chemical fertility

Standard procedures were followed in the collection and analysis of chemical fertility indicators. Measurements of soil pH, Olsen P, exchangeable cations and Cation Exchange Capacity (CEC) were carried out by Hill Laboratories Ltd, Hamilton, as outlined in Table 2. Exchangeable cations are presented using me/100g and quicktest (QT) units. QT units are the soil fertility units most commonly used in New Zealand (Table 3 provides conversion formula).

Table 2: Procedures followed by Hill Laboratories in the chemical fertility analysis of soil.

Analyte	Method
Soil pH	1:2 (v/v) soil:water slurry followed by potentiometric determination of pH.
Olsen P	Olsen extraction followed by Molybdenum Blue colorimetry.
Exchangeable cations (K, Ca, Mg, Na)	1 M neutral ammonium acetate extraction followed by ICP-OES.
Cation Exchange Capacity (CEC)	Summation of extractable cations (K, Ca, Mg, Na) and extractable acidity.

Table 3: Conversion of MAF QT (quicktest) units to me/100g.

Exchangeable cation	Conversion formula
Potassium (K)	me/100g = K (QT)/20.8/VW
Calcium (Ca)	me/100g = K (QT)/1.29/VW
Magnesium (Mg)	me/100g = K (QT)/23.3/VW
Sodium (Na)	me/100g = K (QT)/53/VW

VW = the weight of a known volume of air-dried and ground soil (typically 0.9-1.0 for soil used within this project).

2.3.10   Mineral N

Mineral N is a measure of the amount of plant available nitrogen in the soil at the time of sampling. Mineral N was measured using an auto analyser technique, after 5 g of soil (<4 mm; air-dried at 25°C) was extracted with 25 mL of 2 M KCl.

2.3.11   Anaerobically mineralisable N

Anaerobically mineralisable N (AMN) is an estimate of the amount of plant available nitrogen likely to be released to the crop during the current season. AMN was measured on samples that were sieved <4 mm and air-dried at 25°C. AMN was determined following incubation of soil under waterlogged (i.e. anaerobic) conditions at 40°C for 7 days (Keeney 1982), corrected for ammonium in the non-incubated soil. In this method, 5 g of soil was extracted with 50 mL of 2 M KCl. Ammonium in the extracts was measured using an auto analyser technique.

2.3.12   Potentially mineralisable N

Potentially mineralisable N reflects N supply over a growing season under conditions of optimum temperature and moisture. Briefly, 5 g of soil (<4 mm and air-dried at 25°C) is adjusted to moisture content at approximate field capacity, covered and incubated at 20°C for 56 days. At the end of the incubation the soil is extracted with 25 ml KCl and analysed for mineral N using an auto analyser technique. Potentially mineralisable N is calculated by correcting incubated mineral N for initial mineral N measured from a separate sample at the start of the incubation.

2.4   Incubation study

Soil from the Lincoln arable crop trial site was collected, passed through a 4 mm sieve and partially air-dried to approximately 15% moisture content. Sub-samples of the soil were weighed into plastic pots and adjusted to either of two moisture content treatments: 90% of field capacity (at -5 kPa), or 15% (w/w, approx. irrigation trigger point). The pots of soil were sealed into airtight plastic containers (five pots of soil per container) and incubated for 5 days at 20°C to allow the soils to adjust to the change in temperature before compost was added.

At the end of the 5 days the containers were opened and the compost treatments applied. Compost was applied at two rates equivalent to 0 and 25 t/ha soil-incorporated. The weighed amount of compost was mixed with the soil in the pot then lightly packed down to a bulk density of 1.1 cm^3. The pots of soil plus compost were then sealed into the plastic containers and incubated for 90 days. Pots were incubated at one of four constant temperature treatments, 5, 12, 18 or 25°C, for the duration of the study (one incubator at each temperature). Four replicates of each of the treatments were used.

Throughout the incubation period, gas samples were collected by inserting a needle through a rubber septa fitted into the lid of the container and drawing a sample into a gas-tight syringe. The gas samples were then analysed for CO_2 by injection into an infra-red gas analyser (LICOR LI-7000 CO_2/H_2O analyser), and for N_2O by injection into a gas chromatograph equipped with an electron capture detector (Shimadzu GC-17 A). Following collection of gas samples the containers were opened to allow fresh air in; this prevented depletion of oxygen or excessive build-up of CO_2 which would adversely affect microbial activity in the soil/compost.

At the start and at five points during the incubation one of the five pots was removed from each of the containers, the soil/compost passed through a 4 mm sieve and analysed for mineral nitrogen on an auto analyser following a KCl extraction.

The compost used in this study was supplied by Living Earth, Christchurch, and had a total N content of 2.1%. The soil used had a total N content of 0.18%.

C and N Mineralisation rates at days 3 and 75 were analysed using ANOVA, C rate analysed on natural Scale, N rate on log scale. Full 4-way interaction terms are statistically significant in both cases. Cumulative C and N mineralised were both analysed by ANOVA on the log scale.

Amount of Mineral N and the concentration of NH_4 and NO_3 over the 89-day incubation were analysed by repeated measures ANOVA. Each of these were assessed on the natural scale. Once again, the residual degrees of freedom for these analyses are quite high, so results should be interpreted conservatively. Analyses were carried out in GenStat v.12. Figures were prepared using SigmaPlot v.10.

2.5   Trial site selection

The Karina Downs forage and pasture trials were established on a dryland shallow stony soil with reasonably high background soil fertility and physical condition. The site for the Lincoln arable crop trial was carefully selected to provide a site that was not only typical for Canterbury arable cropping situations, but also complementary to Karina Downs (e.g. irrigated, deep free draining soil, low fertility and physical soil condition), as well as providing an alternative cropping rotation to widen the land use spectrum of our compost research. The Pasture trial at Karina Downs was established in 2007 on a dryland sheep/beef grass sward. The Ex-forestry demonstration site at Bankside was established in 2009 on an ex-commercial forestry (*Pinus radiata*) site. During late 2011 a further trial was established on an intensive vegetable production property at Marshlands, north Christchurch. The experimental design and management of each trial site is briefly explained below. A more detailed description of trial management can be found in Horrocks et al. 2011.

2.6   Forage Crop Trial, Karina Downs

The Forage Crop Trial at Karina Downs was originally established in 2007 as a fully replicated trial with 28 plots in an extended Latin Square design (Figure 1). When planning the trial it was thought that there was potential for trends in both directions across the trial site as a result of depth to gravels and orientation of strip grazing. The extended Latin Square layout was designed to account for this as much as possible. A Latin Square design ensures that each treatment occurs once in each row and in each column so that any treatment effect cannot be attributed to inherent variation at the trial site. Since four replicates were not considered sufficient for a trial with four treatments, the Latin Square design was extended to include seven complete replicates of each of the four treatments.

The 2010 oats data were modelled using a mixed model fitted with REML. The analysis accounted for row and column effects as part of the inherent variability in the trial. Treatment means were estimated, and an estimate of the variability associated with these means provided by the Least Significant Difference (LSD) at the 5% level. Data were restricted to include only information from the current year, which is reflected in the presentation of results. All analyses were carried out in GenStat v.12 (VSN International). Where data are presented graphically, the mean response to compost and its LSD is added to results given for prior years, allowing straightforward assessment of any change in treatment response since the trial outset. There was no evidence that a log transformation improved the fit of the model. The 2011 rape data were modelled by Analysis of Variance (ANOVA), and treated as a full 2 x 4 factorial with three reps. Treatment means were estimated, and an estimate of the variability associated with these means provided by the Least Significant Difference (LSD) at the 5% level. All analyses were carried out in GenStat v.12 (VSN International). Results are presented in graphical format and in a table where appropriate.

Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7
25 t/ha 4	50 t/ha 5	0 t/ha 12	100 t/ha 13	100 t/ha 20	0 t/ha 21	50 t/ha 28
100 t/ha 3	0 t/ha 6	50 t/ha 11	25 t/ha 14	25 t/ha 19	50 t/ha 22	100 t/ha 27
50 t/ha 2	25 t/ha 7	100 t/ha 10	0 t/ha 15	0 t/ha 18	25 t/ha 23	0 t/ha 26
0 t/ha 1	100 t/ha 8	25 t/ha 9	50 t/ha 16	50 t/ha 17	100 t/ha 24	25 t/ha 25

Figure 1: Original layout of the forage crop trial, with seven replicates of four compost treatments in an extended Latin Square design.

One-off applications of compost (supplied by Transpacific Industries, Timaru) were surface broadcast on to a fallow Templeton shallow silt loam paddock in November 2007 at four treatment rates (0, 25, 50, 100 t/ha, wet weight basis) to 20 m x 40 m plots. The compost was analysed to determine composition (Table 4). During August 2010 the decision was made to apply further compost to some plots to measure the crop response to a small application top-up following the main application 3 years earlier. This resulted in the trial design being modified slightly, with four plots being removed to balance the replication (Figure 2). The decision was made to apply two applications of 12.5 t/ha to half the plots. The first of these applications was made in November 2010 prior to the rape being sown. The second was made in October 2011 prior to the grass being established.

Table 4: Laboratory analysis of the compost applied during the establishment of the arable and forage crop trials, dry weight basis.

Measurement	Arable trial	Forage trial
pH	-	7.7
Organic matter (%)	37.1	49.1
Total Carbon (%)	21.5	28.5
Total Nitrogen (%)	2.06	2.52
C:N ratio	10.5	11.3
Dry matter (%)	48.9	51.2
Total Phosphorus (%)	0.42	0.46
Total Sulphur (%)	0.25	0.25
Total Potassium (%)	1.4	1.27
Total Calcium (%)	2.1	2.1
Total Magnesium (%)	0.43	0.37
Total Sodium (%)	0.16	0.49
Total Iron (mg/kg)	9890	8750
Total Manganese (mg/kg)	302	399
Total Zinc (mg/kg)	459	274
Total Copper (mg/kg)	47	39
Total Boron (mg/kg)	34	26
Total Chromium (mg/kg)	27.1	20.3
Total Arsenic (mg/kg)	16.9	15.9
Total Lead (mg/kg)	141.4	254
Total Nickel (mg/kg)	11.5	6.4
Total Mercury (mg/kg)	0.06	0.07
Total Cadmium (mg/kg)	0.47	0.47

Block One			Block Two	Block Three		
25 t/ha + 4	50 t/ha 5	0 t/ha 12		100 t/ha 20	0 t/ha + 21	50 t/ha + 28
100 t/ha 3	0 t/ha + 6	50 t/ha + 11	Old block 4 now excluded	25 t/ha + 19	50 t/ha 22	100 t/ha 27
50 t/ha + 2	25 t/ha 7	100 t/ha + 10		0 t/ha + 18	25 t/ha 23	0 t/ha 26
0 t/ha 1	100 t/ha + 8	25 t/ha 9		50 t/ha 17	100 t/ha + 24	25 t/ha + 25

Figure 2: Modified layout of the forage crop trial, with three replicates of eight compost treatments. Plots marked with '+' received two additional 12.5 t/ha applications of compost.

There were six crops grown during the duration of the forage crop trial. The sequence and details for each crop in the rotation is shown in Table 5. All crops were direct drilled.

Table 5. Cropping rotation of the forage crop trial.

Crop	Cultivar	Sowing	Grazing	Harvest
Kale	'Sovereign'	November 2007	June–September 2008 (beef cattle)	-
Kale	'Sovereign'	November 2008	May-June 2009 (dairy heifers)	-
Barley	'Tavern'	July 2009	-	February 2010 (grain)
Oats/ryegrass	Unknown (oats), 'Moata' (ryegrass)	February 2010	June–August 2010	November 2010 (silage)
Rape	'Greenland'	November 2010	February 2011 (lambs), July–August 2011 (bulls)	-
Grass	Unknown	October 2011	January 2012 (bulls)	-

Standard fertiliser rates were applied across all treatments for the first four crops. During the final two crops, the plots which received a top-up application of compost received a lower rate of N fertiliser. The forage crop trial was primarily managed by the farmer, Andrew Kerr, with some agronomy advice and input from Plant & Food Research.

2.7 Pasture Trial, Karina Downs

The Pasture Trial was designed as a simple presence/absence trial with three replicates of two treatments (no compost, 50 t/ha compost) in a randomised trial (Figure 3). Any interpretation of trial results should bear in mind the low number of observations. Compost was supplied by Transpacific Industries, Timaru.

The data were analysed using Analysis of Variance. Potential correlations between measurements at consecutive sampling occasions were assessed within the REML modelling process, but there was no indication that consecutive measurements were correlated with previous results. As such, there was no evidence to include a correlation structure in the final model. Analyses were carried out in GenStat v.12. Figures were prepared using SigmaPlot v.10. An estimate of the variation associated with predicted means is given by the 5% LSD.

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Block One		Block Two		Block Three	
0 t/ha compost	**50 t/ha compost**	**50 t/ha compost**	**0 t/ha compost**	**0 t/ha compost**	**50 t/ha compost**
plot 1	*plot 2*	*plot 3*	*plot 4*	*plot 5*	*plot 6*

Figure 3: The strip design layout of the pasture trial.

The pasture trial had fewer measurements than the forage crop trial. Compost was broadcast-applied to a fallow Templeton shallow silt loam paddock at either 0 or 50 t/ha (fresh weight) in 28 September 2007, to 80 m x 29 m plots, then direct drilled into Italian ryegrass.

The aim of this trial was to compare standard new pasture N fertiliser management with plots treated with compost rather than base fertiliser. The N fertiliser applications throughout the trial were applied to both treatments.

This trial was grazed by sheep on three occasions between December 2007 and March 2008. During winter and spring 2008 it was confirmed that some areas were infested with grass grub and would have to be re-sown. The trial area was heavy rolled in early October 2008, but the timing is thought to have been too late to control grub populations.

The pasture failed to grow during spring 2008 so was sprayed off during early 2009 and direct drilled into a ryegrass sward in March 2009.

Pasture cages were installed in the second sward and dry matter cuts were made under these cages every few weeks from mid-2009 to late 2010. In each case the cage was moved slightly to ensure the grass being measured in the subsequent cut had been exposed as much as possible to typical urine and dung inputs.

Soil measurements were carried out during spring in 2008, 2009 and 2010.

The Pasture Trial was primarily managed by the farmer, Andrew Kerr, with some agronomic advice from Plant & Food Research. All monitoring on this trial was completed in October 2010.

2.8   Arable Crop Trial, Lincoln

The Arable Crop Trial was a detailed trial located at Lincoln and included three replicates of 16 treatments in a full factorial design (total 48 plots, Figure 4). Compost, supplied by Living Earth, Christchurch, was analysed to determine composition (Table 4). The compost was applied in October 2009 at either one-off application rates (0, 25, 50 t/ha), or split application rates (8.3, 16.7 t/ha annually for 3 years, immediately prior to the first three crops being established), depending on the treatment, to 11 m x 20 m plots (Table 7). Following application, in all cases, the compost was incorporated into the top 10 cm of soil.

The irrigated trial was established on a deep stone-free Paparua silt loam of low to moderate soil chemical fertility with a history of continuous cropping. There were four crops grown over the duration of the arable crop trial (to represent a typical Canterbury arable cropping rotation). The sequence and details for each crop in the rotation is shown in Table 6.

Table 6. Cropping rotation of the arable crop trial.

Crop	Cultivar	Sowing	Harvest
Maize	39G12	October 2009	April 2010 (silage)
Wheat	'Excede'	May 2010	January 2011 (grain)
Oats/ryegrass	'Milton' (oats), 'Feast 2' (ryegrass)	March 2011	May and October 2011 (silage)
Peas	'Miami'	October 2011	February 2012 (seed)

In addition to compost rate, four rates of nitrogen fertiliser (0, 33, 67, and 100% of standard rate) were applied. Standard fertiliser rates for this site were determined using soil N test results and Plant & Food Research's crop calculators.

Nitrate leaching measurements were collected during the first two crops using solution sampling tubes installed to 1.5 m depth. Neutron probe tubes (1.5 m depth) and TDR rods (60 cm depth) were installed to measure soil moisture down the profile to allow drainage calculations to be made.

Soil quality measurements were carried out during October 2009 prior to treatments being imposed, then repeated again on numerous occasions throughout the subsequent 3 years

The arable crop trial was managed entirely by Plant & Food Research agronomists and farm personnel.

The effect of nitrogen rate, compost rate and compost timing on plant and soil response variates were modelled using a mixed model fitted with REML with random effects included to control effects of spatial trends. The effect of nitrogen rate and compost rate over the course of the trial were also assessed for some soil response variates. Potential correlations between measurements at consecutive sampling occasions were assessed within the REML modelling process, but were not found to be of sufficient importance to include in the final analysis. Treatment means were estimated, and an estimate of the variability associated with these means provided by the LSD at the 5% level of significance. All analyses were carried out in GenStat v.12 (VSN International). Results are presented in graphical and tabular format. There was no evidence that a log transformation was required.
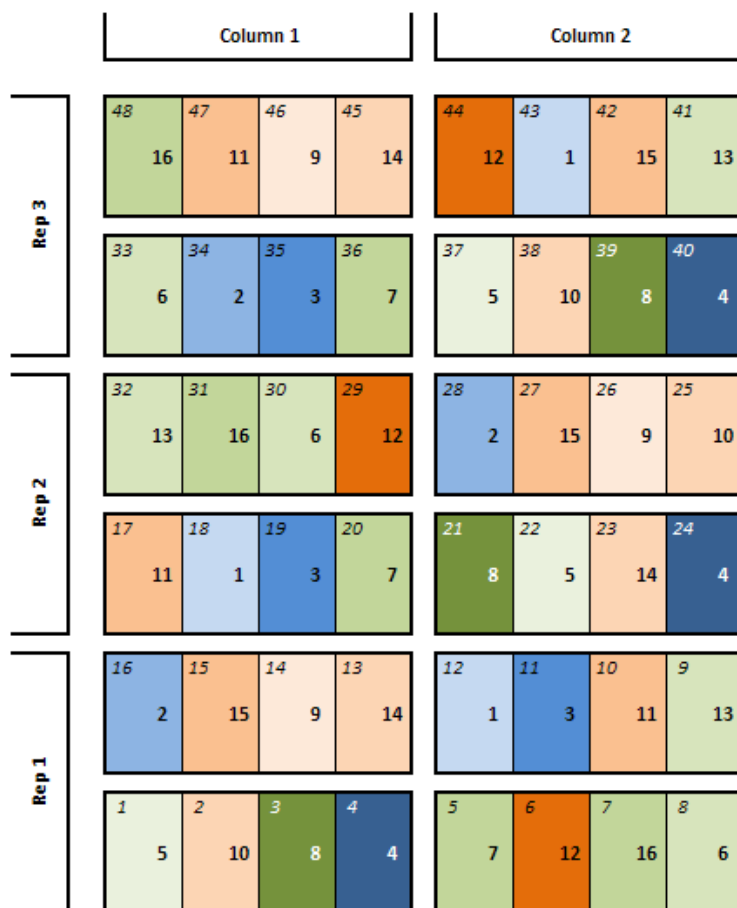
Figure 4: Layout of the arable crop trial, with three replicates of 16 treatments in a full factorial design.

Table 7: Treatment structure at the arable crop trial.

Treatment	Compost rate (t/ha)	% of standard fertiliser N	% compost at crop 1	% compost at crop 2	% compost at crop 3
1	0	0	0	0	0
2	0	33	100	0	0
3	0	66	100	0	0
4	0	100	100	0	0
5	25	0	0	0	0
6	25	33	100	0	0
7	25	66	100	0	0
8	25	100	100	0	0
9	50	0	0	0	0
10	50	33	100	0	0
11	50	66	100	0	0
12	50	100	100	0	0
13	25	33	33	33	33
14	50	33	33	33	33
15	50	66	33	33	33
16	25	66	33	33	33

2.9 Ex-forestry Trial, Bankside

The ex-forestry trial was designed as a simple presence/absence trial with three replicates of two treatments (no compost, 50 kg/ha compost) in a randomised design (Figure 5) similar to that of the pasture trial. The decision was made in 2010 to remove plot 6 from the trial after it became obvious that the soil in that plot was wetter and less stony than the remaining five plots due to being on a slightly lower terrace. Any interpretation of trial results should bear in mind the low number of observations.

The trial site was on a very stony Eyre silt loam on the north bank of the Rakaia River at Bankside, which was converted from long-term exotic forestry approx. 2 years previously.

Compost, supplied by Living Earth, Christchurch, was surface applied at either 0 or 50 t/ha to 100 m x 50 m plots in October 2009. The compost was incorporated into the surface soil and the site drilled into kale ('Gruner') in November. The trial was strip grazed with dairy cattle from late May 2010. During November 2010 the sites was drilled into a second crop of kale ('Kestral') which was strip grazed with dairy cattle from May 2011.

This trial was primarily managed by the farmer, Gary McGregor.

The data were analysed using Analysis of Variance. Analyses were carried out in GenStat v.12. for crop data we only looked at 2nd year data. For soil data a comparison was made between baseline and end of crop 1. Figures were prepared using SigmaPlot v.10. An estimate of the variation associated with predicted means is given by the LSD at the 5 % level of significance.

Block One		Block Two		Block Three	
50 t/ha compost	**0 t/ha compost**	**0 t/ha compost**	**50 t/ha compost**	**50 t/ha compost**	**0 t/ha compost** *(removed from trial design in 2010)*
plot 1	*plot 2*	*plot 3*	*plot 4*	*plot 5*	*plot 6*

Figure 5: The strip design layout of the ex-forestry trial.

2.10 Intensive Vegetable Production Trial, Christchurch

The intensive vegetable production trial was located at Marshlands, a long-term market gardening area on the north side of Christchurch. An extended Latin square layout of 20 plots (five replicates of four treatments; Figure 6) designed to account for spatial trends, ensuring good data could be captured from what is a unique and important land use within the broader Christchurch area. It was also decided to incorporate a chicken manure product used by some growers in the Marshlands area to be able to provide growers with the comparative data they would be interested in.

The trial was established on a stone-free Waimari peaty loam + Waikuku sandy loam complex soil during December 2010 using two rates of compost (14 or 28 t/ha, supplied by Living Earth, Christchurch), and one rate of fresh chicken manure (10 t/ha, supplied by Poulfert Ltd). Amendment rates were based on the standard grower rate of 10 t/ha chicken manure and a compost rate that matched it on a dry weight basis (14 t/ha) and a mineral N content basis (28 t/ha). Control plots were established with the absence of compost or manure amendments. Amendments were applied only once and were soil-incorporated. Both the compost and chicken manure were analysed to determine composition (Table 8).

All plots received equal fertiliser throughout the trial. Fertiliser applied to each crop (banded at time planting) supplied 331 kg N/ha, 44 kg P/ha, 123 kg K/ha, 67 kg S/ha, 34 Ca/ha, and 17 kg Mg/ha. The concentration of nutrients was considerably higher than this within the plant rows where the fertiliser was banded. Three consecutive crops were established during this short trial (Table 9).

This trial was managed by the growers, Ryan and Phil Kiesanowski.

The data were analysed using Analysis of Variance. Figures were prepared using SigmaPlot v.10. An estimate of the variation associated with predicted means is given by the LSD.

Table 8: Laboratory analysis of the compost and chicken manure applied at the intensive vegetable production trial, wet weight basis.

Measurement	Chicken manure	Compost
Total nitrogen (kg/t)	30	14
Mineral N (kg/t)	4.4	1.5
Total phosphorus (kg/t)	11	23
Total potassium (kg/t)	14	48
Total sulphur (kg/t)	2	30
Total calcium (kg/t)	19	155
Total magnesium (kg/t)	4	22
pH	8.4	6.8
C:N ratio	10	9

Table 9. Cropping rotation of the intensive vegetable trial.

Crop	Planting (staggered)	Harvest (staggered)
Lettuces	From December 2010	From February 2011
Cabbages	From March 2011	From August 2011
Lettuces	From December 2011	From February 2012

Figure 6: The extended Latin square design layout of the intensive vegetable production trial. At trial establishment, treatment 1 (T1) received no amendments, T2 received 10 t/ha chicken manure, T3, 14 t/ha compost, and T4, 28 t/ha compost.

2.11 Cost-benefit analysis

The cost-benefit analyses include standard costs of production associated with growing each crop including cultivation, drilling, fertiliser, and the management of weeds, pests and diseases. Fertiliser figures came from the Ballance Agi-Nutrients website (www.ballance.co.nz) and other costs of production came from the Lincoln University financial manual (Pangborn 2010). Amounts used for the sale or grazing of the crops were based on standard rates applicable to the year the crop was grown. Calculations were based on the compost being bought at $12.50/t and being spread at $6.50/ha (figures from Living Earth). Compost spreading costs are based on a farmer contracting out this job rather than doing it themselves. The break-even freight rate ($/t) is the cut-off point above which higher freight costs would not be profitable. Scenarios are considered profitable if returns are greater or the same as standard practice (100% of recommended fertiliser N, recommended as though no compost was to be applied).

3 Results and discussion

3.1 Forage Crop Trial, Karina Downs

Detailed results and discussion for the first 4 years of the forage crop trial have been presented in previous reports (Tregurtha et al. 2008, 2009a, 2009b; Horrocks et al. 2010, 2011). Data from plant and soil variates measured since the Horrocks et al. 2011 report are presented in Tables 10–13.

Table 10: Treatment means with 5% LSD for the soil variates measured at the end of the forage crop trial (autumn 2012) in response to compost rate.

Compost rate applied in 2010 (t/ha)	0	12.5	0	12.5	0	12.5	0	12.5	5% lsd with 14 df
Original compost rate (t/ha)	0	0	25	25	50	50	100	100	
Organic C (%, 0–7.5 cm)	3.59	3.44	3.55	3.87	3.70	4.14	4.35	4.55	0.69
Total N (%, 0–7.5 cm)	0.37	0.36	0.37	0.41	0.37	0.42	0.44	0.47	0.07
C:N (0–7.5 cm)	9.72	9.66	9.65	9.55	9.87	9.86	9.90	9.68	0.31
Organic C (%, 7.5–15 cm)	2.67	2.09	2.57	2.52	2.16	2.49	2.48	2.52	0.60
Total N (%, 7.5–15 cm)	0.31	0.26	0.29	0.31	0.26	0.29	0.30	0.29	0.06
C:N (7.5–15 cm)	8.16	7.69	8.09	7.93	7.91	7.97	8.09	8.05	0.43
Organic C (t/ha, 0–7.5 cm)	33.16	31.92	33.60	36.50	34.06	37.22	38.17	41.32	5.29
Total N (t/ha, 0–7.5 cm)	3.41	3.30	3.48	3.82	3.45	3.78	3.86	4.27	0.54
Organic C (t/ha, 7.5–15 cm)	24.76	20.78	24.35	23.92	21.31	23.68	23.40	24.17	4.30
Total N (t/ha, 7.5–15 cm)	2.73	2. 43	2.70	2.71	2.42	2.67	2.60	2.70	0.38
0–7.5 cm bulk density (g/cm^3)	1.24	1.25	1.27	1.26	1.25	1.23	1.18	1.22	0.06
7.5–15 cm bulk density (g/cm^3)	1.25	1.33	1.27	1.27	1.32	1.29	1.26	1.28	0.09
Aggregate stability (mm, MWD)	2.06	2.12	2.01	1.92	2.17	2.05	2.13	2.00	0.23
Aggregate stability (%>1 mm)	76.74	78.46	73.64	72.01	79.65	75.63	78.08	73.61	7.97
Structural condition score	5.00	4.83	4.67	5.00	4.33	5.17	5.67	4.17	1.51
Moisture content at field capacity (% w/w)	37.01	36.54	35.03	34.42	35.57	36.03	37.95	37.59	3.64
Soil pH	6.17	6.33	6.27	6.33	6.27	6.47	6.47	6.43	0.15
Olsen P (mg/L)	22.33	17.33	23.67	25.33	19.00	32.00	26.67	31.67	13.44
K (me/100g)	0.29	0.25	0.36	0.37	0.26	0.52	0.36	0.48	0.30
Ca (me/100g)	12.33	11.67	11.77	13.10	11.57	12.13	13.67	13.33	1.54
Mg (me/100g)	1.45	1.38	1.39	1.67	1.48	1.56	1.81	1.92	0.26
Na (me/100g)	0.11	0.14	0.10	0.15	0.11	0.14	0.11	0.18	0.02
CEC (me/100g)	18.33	17.00	18.00	19.00	17.00	17.33	19.00	19.33	2.49
K (QT)	4.67	4.00	6.00	6.33	4.33	9.00	6.00	8.00	5.06
Ca (QT)	12.67	11.67	11.67	13.33	12.00	12.67	14.00	13.33	1.44
Mg (QT)	26.67	25.33	25.33	30.67	27.00	29.33	33.33	34.67	4.69
Na (QT)	4.33	5.33	3.67	6.00	4.33	5.00	4.00	6.33	0.75
Mineral Ammonium (0–7.5 cm, g/g)	0.53	0.12	0.88	0.19	0.23	0.62	0.50	1.31	0.84
Mineral Nitrate (0.7–5 cm, µg/g)	18.10	15.75	17.56	14.87	13.87	16.40	20.24	17.05	6.48
Mineral Nitrate (7.5–15 cm, µg/g)	5.02	3.95	3.98	4.36	5.14	6.93	4.18	4.14	2.60
Mineral N (0–15 cm (kg N/ha)	21.88	18.65	21.22	18.30	18.10	21.80	22.04	20.62	6.23

QT = MAF quicktest units

Table 11: Treatment means with 5% LSD for POM measured in spring 2010 and at the end of the trial (autumn 2012) at the forage crop trial in response to compost rate.

Year	2010					2012		2012		2012		2012		
Compost rate applied in 2010 (t/ha)					5% lsd with 14 df	0	12.5	0	12.5	0	12.5	0	12.5	5% lsd with 14 df
Original compost rate (t/ha)	0	25	50	100		0	0	25	25	50	50	100	100	
POM C (t/ha, 0–7.5 cm)	7.6	9.43	9.96	12.19	1.57	7.12	7.81	8.46	9.64	9.94	9.49	11.89	11.67	2.47
POM N (t/ha, 0–7.5 cm)	0.63	0.80	0.84	1.03	0.14	0.48	0.54	0.59	0.68	0.72	0.68	0.85	0.84	0.18
POM C (% of total organic C, 0–7.5 cm)	24.95	27.42	29.22	31.18	3.65	22.07	26.75	24.69	28.75	30.19	27.37	30.29	31.11	6.52
POM N (% of total N, 0–7.5 cm)	19.06	21.22	22.73	24.12	3.41	13.09	15.85	15.06	18.00	19.04	17.14	19.35	19.59	4.03

Table 12: Treatment means with 5% LSD for the plant variates measured in July 2011 from the rape regrowth at the forage crop trial in response to compost rate.

Compost rate applied in 2010 (t/ha)	0	12.5	0	12.5	0	12.5	0	12.5	5% lsd, 14 df
Original compost rate (t/ha)	0	0	25	25	50	50	100	100	
Regrowth (t/ha)	1.20	1.52	1.31	1.23	1.37	1.38	1.29	1.51	0.27
Total DM yield (t/ha)	5.68	7.11	5.60	5.59	5.84	6.38	5.82	7.89	1.24
DM leaf:stem	373.3	501.9	384.8	454.6	432.2	394.3	436.2	378	109.20
Whole plant N content (%)	3.36	3.32	3.21	3.25	3.07	3.41	3.17	3.38	0.26
Whole plant C content (%)	43.3	43.1	43.2	42.9	43	42.8	42.9	42.9	0.49
Regrowth N uptake (kg/ha)	40.3	50.4	42.1	40.2	42.2	47.1	40.2	51.1	9.33
Regrowth C uptake (kg/ha)	519.2	654.8	565.4	530.0	590.0	591.0	554.6	648.7	119
Rape regrowth plant C:N	12.9	13.0	13.5	13.2	14.0	12.6	13.6	12.7	1.09

Table 13: Treatment means with 5% LSD for the plant variates measured in February 2012 from the grass at the forage crop trial in response to compost rate (note that sampling before the first grazing was missed due to communication error with farmer).

Compost rate applied in 2010 (t/ha)	0	12.5	0	12.5	0	12.5	0	12.5	5% lsd, 14 df
Original compost rate (t/ha)	0	0	25	25	50	50	100	100	
DM yield (t/ha)	0.72	0.96	0.75	0.77	0.83	0.96	0.89	1.15	0.24
Moisture content (%)	19.2	17.1	20.4	19.6	18.0	18.5	19.2	18.2	3.51
N content (%)	2.22	2.26	2.03	2.34	2.39	2.35	2.04	2.15	0.43
C content (%)	43.3	43.5	43.4	43.7	42.8	43.2	43.6	43.0	0.66
N uptake (kg/ha)	15.9	21.8	15.7	18.1	20.1	23.2	18.4	24.9	8.51
C uptake (kg/ha)	311.2	418.4	324.5	334.9	357.4	413.0	387.8	493.4	101.9

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3.1.1 Crop yields

The single application of municipal compost applied in 2007 significantly improved dry matter yields of the two consecutive forage kale crops (Figure 7), though the effect diminished for the second kale crop (2008–09). Differences were no longer apparent in the following barley crop grain yield (2009–10) (P = 0.151); however, the effects of the original compost application on mineralisable N were still evident suggesting that offsets to fertiliser may have been possible without compromising yields (this was not tested alongside the one-off compost applications). There were no yield differences at the end of the following oat crop (2010) (P = 0.591, Figure 8).

Figure 7: Mid-season (March 2008) kale crop response at the forage crop trial in response to 0, 25, 50, 100 t/ha compost (a, b, c, and d respectively).

Offsets to fertiliser were not made to this trial until 2010 when a 12.5 t/ha compost top-up was applied to half of the trial (November 2010) and standard N fertiliser rates were reduced by 40%. This reduction in fertiliser alongside the 12.5 t/ha of compost resulted in an 18% increase in yields compared with plots that did not receive the compost top-up (but received the full recommended N fertiliser rate) (P = 0.011). This trend for higher yield with a 12.5 t/ha compost top up was also carried over to the rape re-growth (P = 0.081) although overall re-growth yields were low. The second 12.5 t/ha compost top-up was applied in October 2011 but the first grass crop measurements were missed due to an error in communication with the farmer. Sampling before the second grass grazing did take place and yields were slightly greater with a compost top-up of 12.5 t/ha (P = 0.012); however, the overall re-growth was low across all treatments (less than 0.9 t/ha, Figure 8).
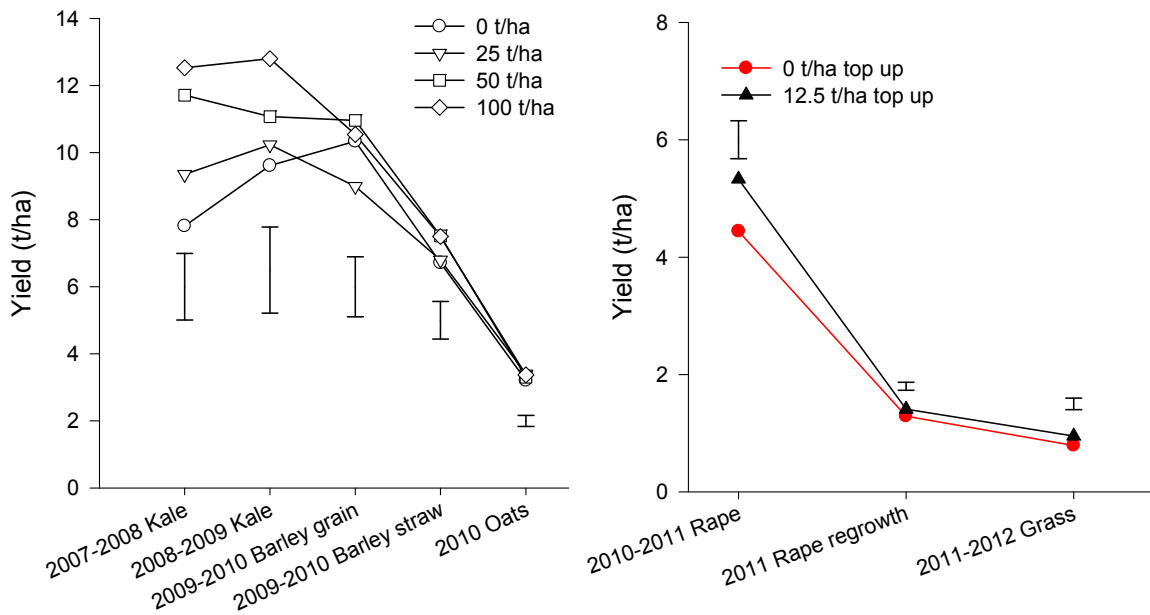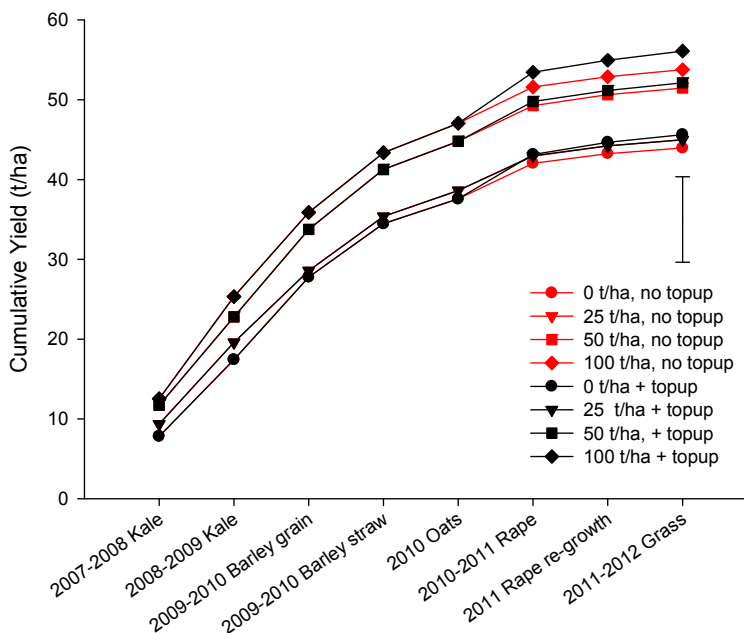
Figure 8: Effects of one-off compost treatments and a 12.5 t/ha top-up compost treatment on the dry matter yield at the forage crop trial. Bars represent 5% LSD with 18 df.

It is likely that there was the potential to offset fertiliser applications alongside the original 2007 one-off applications, and although the trial is now complete available N results suggest that offsets to fertiliser without compromising yields would be likely in the following crop. These results suggest that the higher the application rate the higher the yield improvement (Figure 9), and that reapplications should be considered after 3–4 years. Smaller applications of compost accompanied by reductions in fertiliser N can also result in yield improvements.

Figure 9: Effects of one-off compost treatments and a 12.5 t/ha top-up compost treatment on the cumulative dry matter yields at the forage crop trial. Bar represents 5% LSD with 14 df.

Results for N uptake follow a similar pattern to yield. After the first kale crop following the one-off application of compost in 2007 the uptake of N increased with compost rate ($P < 0.001$).
This diminished in the following years, especially for rates less than 100 t/ha (Figure 10). Although there was a trend for the compost top-ups in 2010 and 2011 to increase N uptake in the subsequent crops (Figure 10) this was only significant for the rape re-growth ($P = 0.018$) and not the initial grazing ($P = 0.259$).
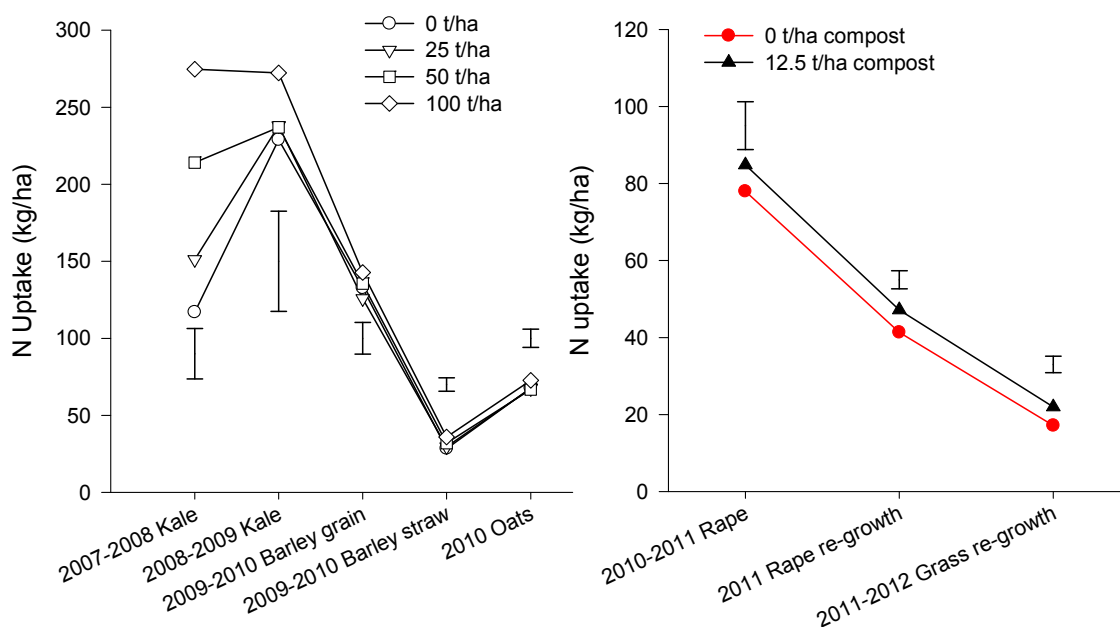
Figure 10: Effect of compost on N uptake (kg/ha) at the forage crop trial from 2007 to 2012. Bars represent 5% LSD with approx. 18 df.

3.1.2   Soil chemical fertility

Throughout the trial there was a strong effect of compost on soil total N (t/ha) and available N (AMN) in the top 7.5 cm (Figure 11). This was still strongly apparent at the end of the trial in 2012 ($P = 0.011$ and $P = 0.003$ respectively). Our results suggest that offsets to fertiliser N would have been plausible without compromising yields right up to the end of the trial. There was no difference in soil total N (t/ha) or available N (AMN) in the top 7.5 cm between the 'with' and 'without' compost top-up suggesting that reducing fertiliser N by 40% where the top-up was applied did not compromise total or available N.
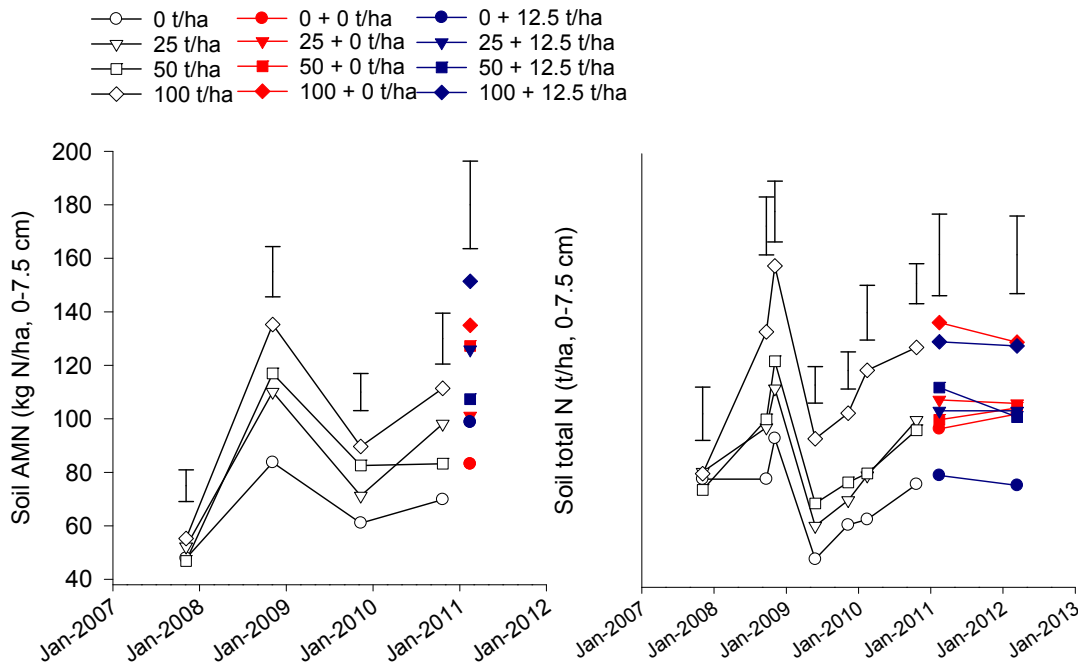
Figure 11: Effects of one-off compost treatments and a 12.5 t/ha top-up compost application on soil AMN and soil total N at the forage crop trial from 2007 to 2012. Bars represent 5% LSD with approx. 16 df.

Throughout the duration of the trial there was a strong effect of the one-off application of compost on phosphorus (P) and cation exchange capacity (CEC) with Olsen P (mg/L) and CEC (me/100 g) values both increasing with increases in the rate of compost applied (Figure 12). This effect was still apparent in 2010 at the end of the barley (P = 0.04 and P = 0.02 respectively). By the end of the trial in 2012 there were no longer any carry over effects from the one-off applications of compost for P or CEC (P = 0.257 and P = 0.118 respectively). Adding 12.5 t/ha top up had no effect in the first or second year for either P (P = 0.897 and P = 0.262 respectively) or CEC (P = 0.199 and P = 0.888 respectively).
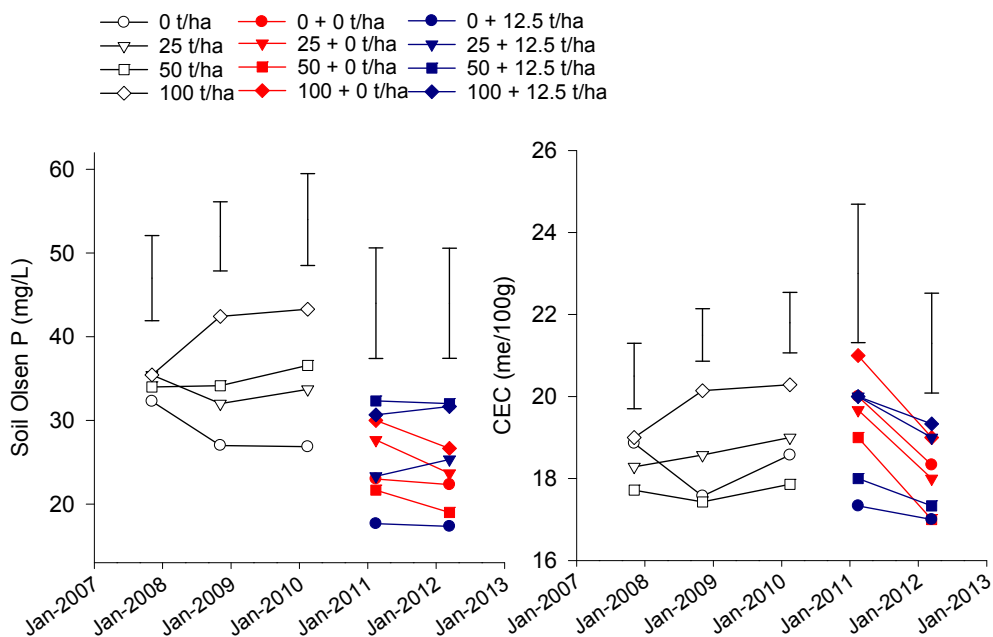

Figure 12: Effects of one-off compost treatments and a 12.5 t/ha top-up compost application on Olsen P and Cation Exchange Capacity (CEC) at the forage crop trial from 2007 to 2012. Bars represent 5% LSD with approx. 16 df.

Throughout the duration of the trial there was an effect of the one-off application of compost on quicktest potassium (K) with trends of higher values the higher the compost rate still apparent in 2010 (Figure 13). By the end of the trial in 2012 the original one-off compost applications were no longer having an effect (P = 0.415) and neither were there any effects of the 12.5 t/ha top-ups in the first or second year (P = 0.491 and P = 0.201). Calcium (Ca), on the other hand, was still significantly higher at the end of the trial where 100 t/ha of compost had been applied (P = 0.002) but similar to K there was no effect of the top-ups in either the first or second year (P = 0.626 and P = 0.829, respectively).
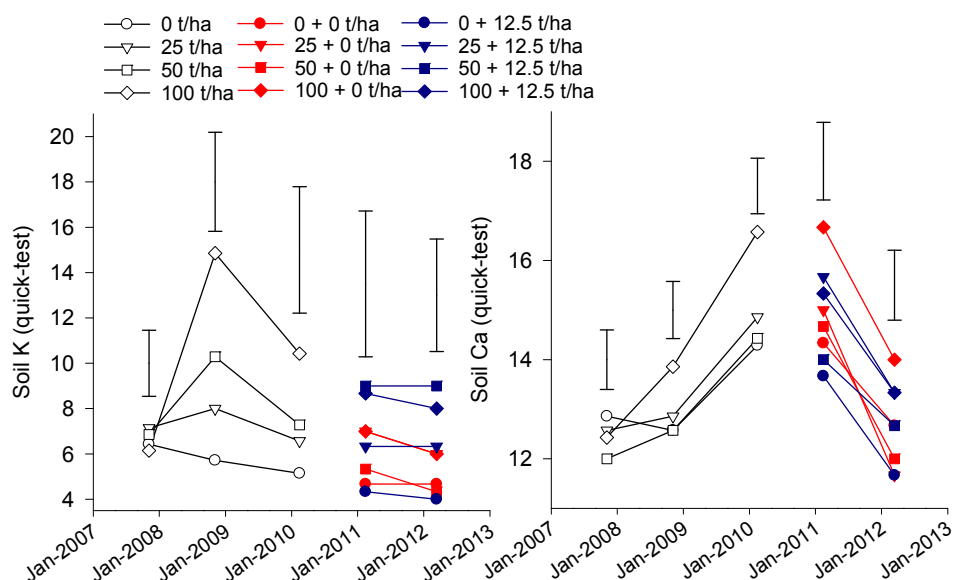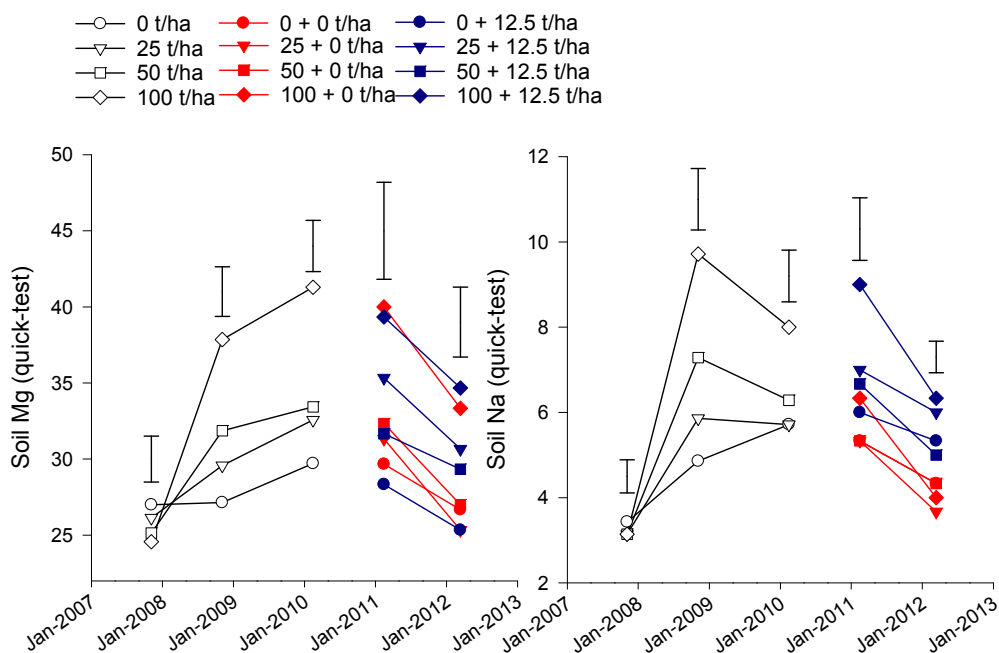

Figure 13: Effects of one-off compost treatments and a 12.5 t/ha top-up compost application on soil quicktest K and Ca at the forage crop trial from 2007 to 2012. Bars represent 5% LSD with approx. 16 df.

Throughout the duration of the trial there was an effect of the one-off application of compost on quicktest magnesium (Mg) with higher Mg quicktest values the greater the rate of compost applied. This was still apparent in 2012 (P < 0.001, Figure 14). A similar result was found for quicktest sodium (Na) although it was no longer apparent in 2012 (P = 0.276). There was no effect of the 12.5 t/ha compost top-up in first and second year for Mg (P = 0.829) or (P = 0.102) but there was for Na (P < 0.001 for both years).

Figure 14: Effects of one-off compost treatments and a 12.5 t/ha top-up compost application on soil quicktest Mg and Na at the forage crop trial from 2007 to 2012. Bars represent 5% LSD with approx. 16 df.

These results suggest that the 12.5 t/ha top-up application rate was too low to have an effect on P, CEC, K, Ca and Mg, but it did increase Na levels. The one-off applications did have strong carry over effects for these nutrients, for some right up to 2012. This was more evident the greater the rate of compost originally applied.

3.1.3 Carbon, soil structure and water holding capacity

One of the primary determinants of good soil structure is a relatively high organic matter content. It is the primary source of food for soil organisms, improves the water holding capacity of soil, releases nutrients (e.g. nitrogen, sulphur, phosphorus) during decomposition, and contributes to the development and maintenance of good soil structure. Due to compost being made up of around 30% total C, it is not surprising that soil organic matter content increased with the rate of compost applied (Figure 15). There is strong evidence to suggest that the original one-off application of compost in 2007 was still having an effect on C levels ($P = 0.006$) at the end of the trial with organic C % in the top 7.5 cm of soil increasing with the rate of compost that was applied. Applying an additional 12.5 t/ha compost in 2010 and 2011 had no effect on the C % in the top 7.5 cm after either the first ($P = 0.661$) or second application ($P = 0.222$). Over the duration of the trial there was no evidence that one-off applications of compost or 12.5 t/ha top-ups had any effect on soil physical parameters of aggregate stability or soil condition score (SCS). Bulk density decreased with compost but only with the 100 t/ha one-off application rate (Figure 16). There was still some evidence of a compost effect for the 100 t/ha one-off application rate at the end of the trial ($P = 0.062$).
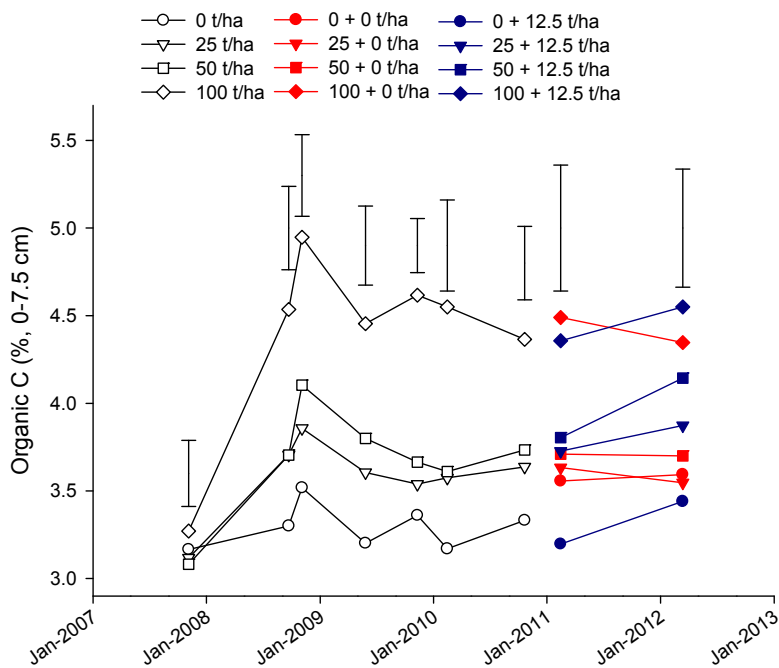
Figure 15: Effects of one-off compost treatments and a 12.5 t/ha top-up compost application on 0–7.5 cm depth soil organic C content (%) at the forage crop trial between 2007 and 2012. Bars represent 5% LSD with approx. 16 df.

Throughout the first 3 years of the trial there was a strong effect of the one-off application of compost at the 100 t/ha rate on soil water holding capacity (Figure 16). This became less apparent after the first 12.5 t/ha compost top up ($P = 0.091$). There were no top-up effects on water holding capacity after either the first ($P = 0.646$) or second ($P = 0.775$) application. These results suggest that high rates of compost are required before increased soil carbon leads to improved soil structure. It is possible that after sustained applications of smaller rates (<50 t/ha) improvements to soil physical parameters such as aggregate stability may become apparent.
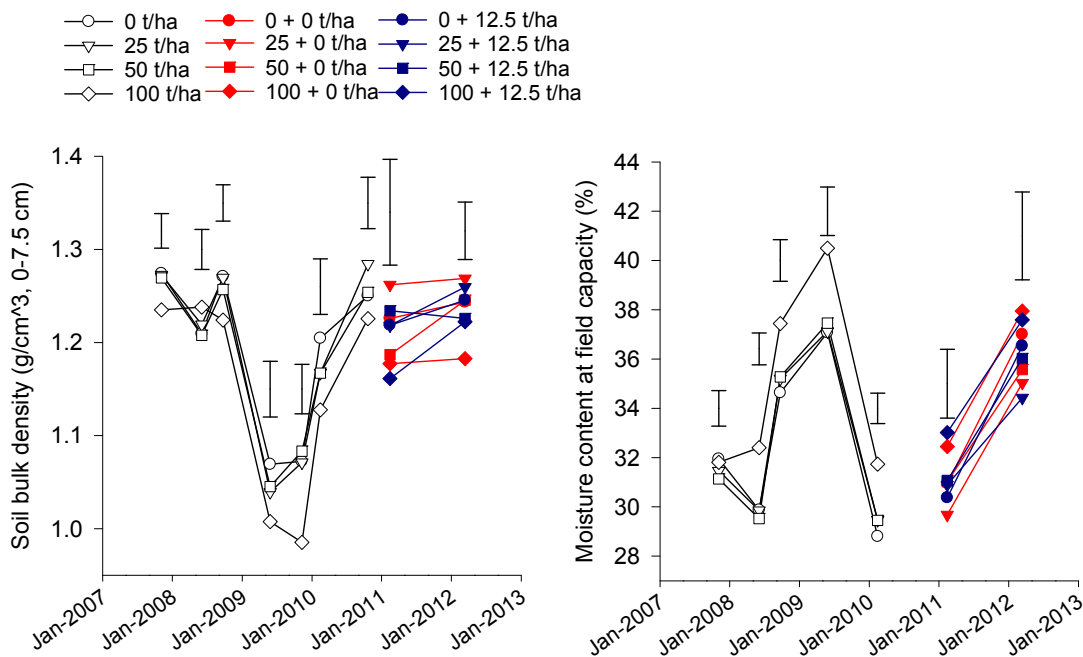

Figure 16: Effects of one-off compost treatments and a 12.5 t/ha top-up compost application on soil bulk density and moisture content at field capacity at the forage crop trial from 2007 to 2012. Bars represent 5% LSD with approx. 16 df.

3.1.4 Particulate organic matter (POM)

POM is thought to be closely associated with N availability because it contains much of the partially decomposed plant material that fuels mineralisation (Willson et al. 2001). It is thought to represent a labile pool of soil organic matter (SOM) and it has been suggested it is a sensitive indicator of changes of SOM because of its responsiveness to management practices (Marriott & Wander 2006).

Baseline POM at the forage crop trial was consistent across the trial site at the time of baseline sampling (Figure 17). Where compost was applied the POM content has increased. This is to be expected given that a large fraction of the compost is POM (Willson et al. 2001; Fortuna et al. 2003; Marriott & Wander 2006).

The first two crops (kale) resulted in both POM C and N behaving in a similar way, with both increasing with increasing rate of applied compost. By 2011 at the end of the fifth crop (rape) the % of organic C and N that was in the form of POM C and N was still greater in the top 0–7.5 cm (P = 0.058 and P = 0.012 for C and N, respectively). There was no indication that the 12.5 t/ha compost additions had any effect on % C or % N POM (P = 0.287 and P = 0.293, respectively). There is a strong correlation between the compost-induced yield improvements in 2008 and 2009 and the significantly greater POM values. This is because POM is correlated with the labile and readily available potentially mineralisable N.

POM results for C and N show similar trends to available N results in that both were still greater where compost had been applied after yield differences were no longer occurring. These results suggest that fertilisers could have been reduced (where compost had been added) during and beyond the time frame of this trial without compromising yields.
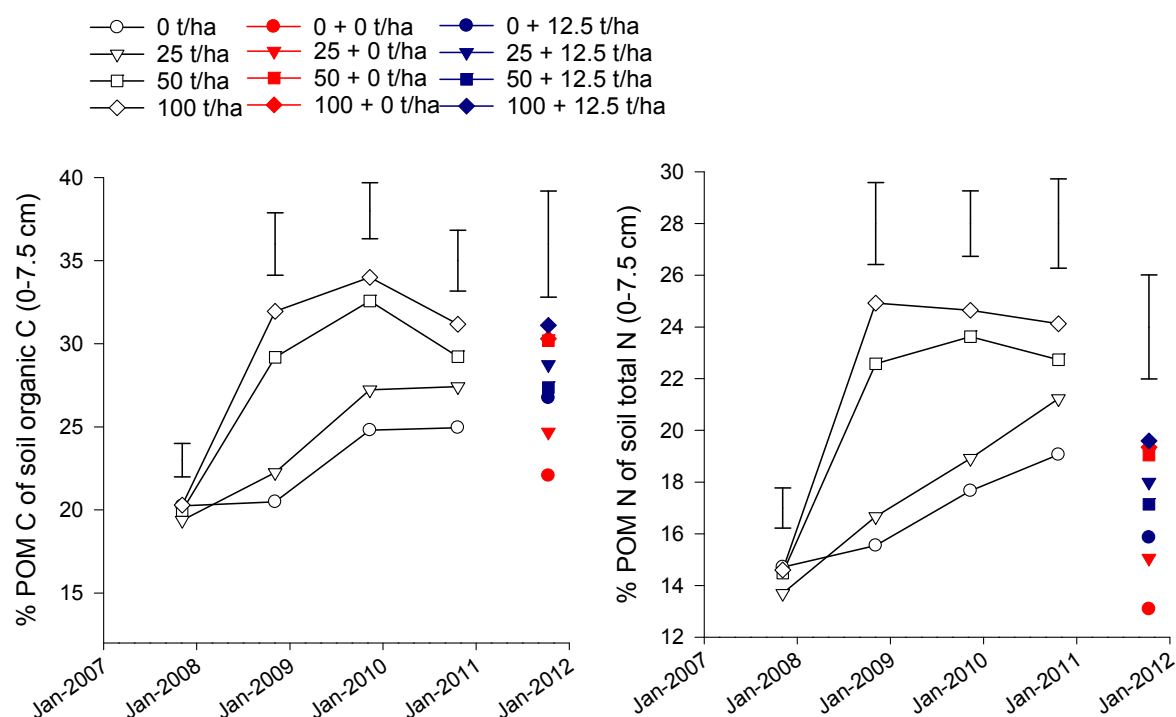

Figure 17: Effects of one-off compost treatments and a 12.5 t/ha top-up compost application on POM C from the total soil organic C pool and POM N from the soil total N pool (0–7.5 cm) at the forage crop trial. Bars represent 5% LSD with approx. 16 df.

3.2 Pasture Trial, Karina Downs

Detailed results and discussion for the first 4 years of the pasture trial have been presented in previous reports (Tregurtha et al. 2008, 2009a, 2009b; Horrocks et al. 2010, 2011).

Compost was applied to the treated plots as a one-off application of 50 t/ha in place of the 200 kg/ha SuperTEN (superphosphate) fertiliser applied to the control plots. Grass production and vigour were found to be markedly greater in compost-treated plots than the control plots throughout the season. As can be seen in Figure 18 the overall grass yield was greater with compost for both swards (sward one was grazed between December 2007 and March 2008 after which grass grub damage meant the crop had to be re-sown and the second sward was grazed between March 2009 and October 2010).
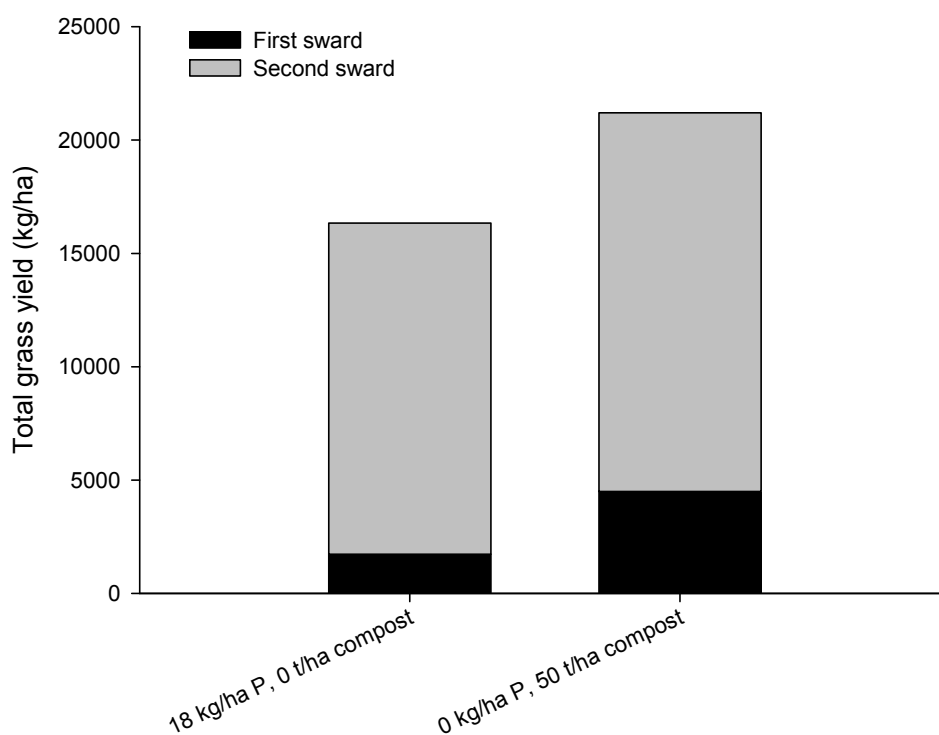

Figure 18: Effects of compost treatment on total grass dry matter during the first and second sward at the pasture trial (2007–10).

Figure 19 illustrates how the rate of grass growth (kg/ha/day) was most significantly boosted by compost when the growth rate peaked in December 2009. A similar pattern emerged in 2010 though the growth rate reached 2009's peak earlier in the season (October). These peaks suggest that compost can provide the extra nutrients required during periods of high demand and this buffering is still apparent 3 years after the one-off application of compost.
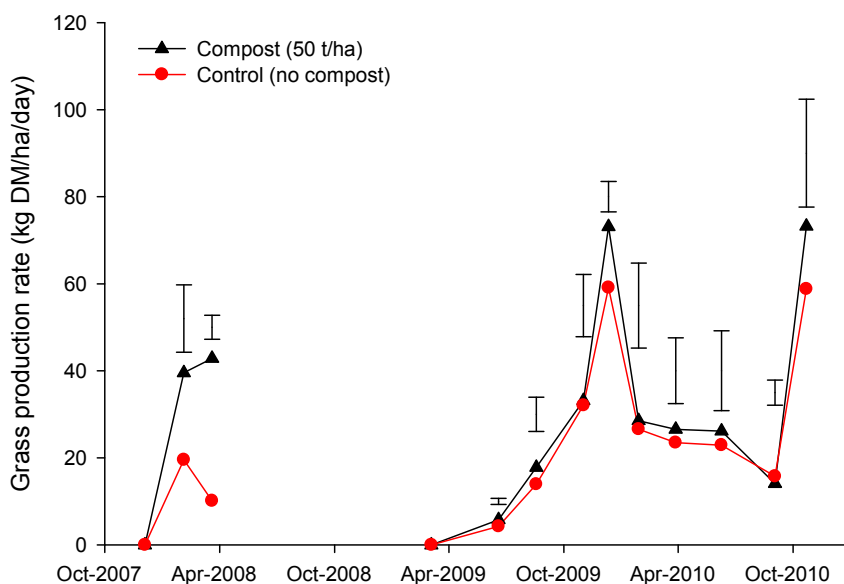
Figure 19: Effects of compost treatment on grass dry matter growth rates during the first and second sward at the pasture trial. Bars represent 5% LSD with 2 df.

During the second grass sward (2009–10) at the pasture trial there was an increase of over 2000 kg or 14% in the cumulative dry matter production in the plots that had received 50 t/ha compost in 2007 when compared with plots that had received no compost. While this was lower than the initial benefits that were measured from the compost in the first sward (Tregurtha et al. 2009b) it does highlight that up to 3 years following a single application of compost a grass pasture can still obtain benefits. It also highlights that the phosphorous available in compost can offset superphosphate fertiliser use.

The high variability and low degrees of freedom in the pasture trial meant that the soil variate results were not significant over the duration of the trial from 2007 to 2010. There are, however, notable trends represented in Figures 20 and 21. Figure 20 shows a trend of greater soil C and N (%) a year after compost was applied (in spring 2008) but these increases were no longer apparent in subsequent years (P = 0.833 and P = 0.707, respectively).
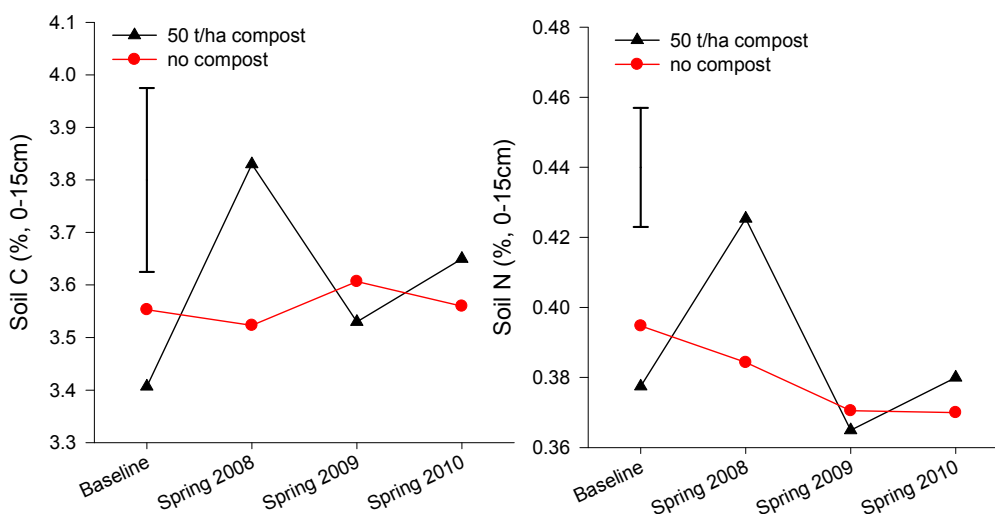

Figure 20: Effects of one-off compost treatments on 0–15 cm depth soil organic C and soil N content (%) at the pasture trial between 2007 and 2010. Bars represent 5% LSD with 12 df.

Figure 21 shows that the more labile pool of soil organic matter (as represented by POM) trends towards being greater where compost was applied compared with where no compost was applied for 3 years after its application.
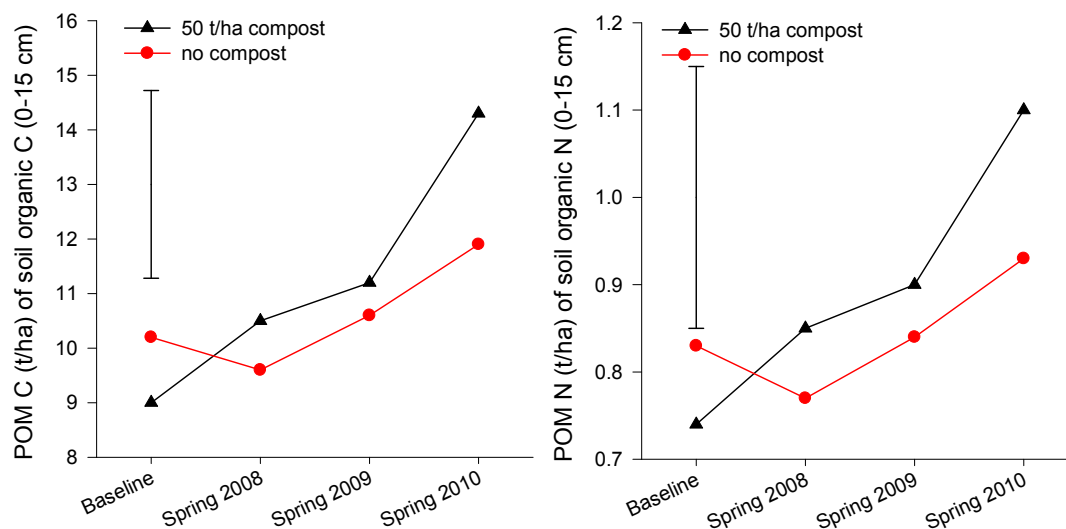

Figure 21: Effects of one-off compost treatments on POM C from the total soil organic C pool and POM N from the soil total N pool (t/ha, 0–15 cm) at the pasture trial. Bars represent 5% LSD with 8 df.

3.3   Arable Crop Trial, Lincoln

Detailed results and discussion for the first 2 years of the arable crop trial have been presented in previous reports (Horrocks et al. 2010, 2011). Data from plant and soil variates measured at the end of the arable crop trial (Autumn 2012) are presented in Tables 14–17.

Results from this trial are discussed in two sections. The first outlines the overall comparisons between the one-off application of 0, 25 and 50 t/ha compost with the 0, 33, 67 and 100% recommended N fertiliser rates. The second outlines the overall comparisons between the one-off application of 25 and 50 t/ha compost with the split applications of 25 and 50 t/ha compost restricted to the 33% and 67% recommended N treatment rates.

Table 14: Treatment means with 5% LSD for each plant variate measured at the end of the oat/grass crop (2011) at the arable crop trial in response to compost rate and N fertiliser.

Compost rate (t/ha)	0	25	50	0	25	25 split	50	50 split	0	25	25 split	50	50 split	0	25	50	5% lsd 22 df	Split 5% lsd 14 df
N (% of standard rate)	0	0	0	33	33	33	33	33	67	67	67	67	67	100	100	100		
Oat + grass dry matter yield (t/ha)	3.7	3.6	4.9	4.0	4.6	5.29	5.2	5.01	4.6	5.5	6.56	5.9	6.56	5.2	5.0	6.5	1.33	1.57
N uptake, oats (kg/ha)	70.2	66.8	103.6	72.7	78.8	92.0	87.2	80.4	70.1	87.9	114.3	91.7	112.3	60.9	61.0	83.6	30.4	30.4
N uptake, grass (kg/ha)	18.3	17.9	20.8	29.5	37.4	40.0	38.4	37.2	47.8	54.0	66.0	55.7	59.4	67.1	65.4	82.5	14.9	14.9
Organic C, oats (%)	3.01	2.86	3.19	3.46	3.32	3.36	3.13	3.18	3.45	3.45	3.69	3.45	3.47	3.72	3.46	3.60	0.46	0.46
Organic C, grass (%)	43.20	42.90	42.60	43.07	42.97	42.87	43.00	43.00	43.30	43.20	43.00	43.13	43.03	43.20	43.30	43.30	0.29	0.29

Table 15: Treatment means with 5% LSD for each plant variate measured at the end of the pea crop (2012) at the arable crop trial in response to compost rate and N fertiliser.

Compost rate (t/ha)	0	25	50	0	25	25 split	50	50 split	0	25	25 split	50	50 split	0	25	50	5% lsd 28 df
N (% of standard rate)	0	0	0	33	33	33	33	33	67	67	67	67	67	100	100	100	
Pea seed yield (t/ha, 14%)	5.70	5.94	6.16	6.13	6.05	6.40	6.24	6.59	6.19	5.62	6.98	6.04	6.62	5.80	5.81	6.28	1.34
Straw DM yield (t/ha)	3.43	3.63	3.89	3.62	3.57	3.93	3.83	3.80	3.76	3.49	4.47	3.76	4.13	3.60	3.58	4.00	0.78
Total DM yield (t/ha)	9.13	9.57	10.05	9.75	9.62	10.33	10.07	10.38	9.94	9.12	11.45	9.80	10.76	9.39	9.39	10.27	2.1
Thousand seed weight (g)	267	262	271	271	270	269	266	277	273	274	271	275	270	276	276	278	12.5
Seed C content (%)	42.70	42.73	42.50	42.63	42.77	42.40	42.17	42.40	42.83	43.13	43.03	42.57	42.63	42.60	42.60	42.73	0.56
Seed N content (%)	3.49	3.48	3.45	3.53	3.54	3.38	3.34	3.48	3.57	3.61	3.33	3.38	3.36	3.47	3.37	3.54	0.20
Total N uptake (kg/ha)	222	235	238	239	237	241	235	252	246	226	260	227	250	223	219	249	55.5

Table 16: Treatment means with 5% LSD for each soil variate measured at the end of the oat/grass crop (2011) at the arable crop trial in response to compost rate and N fertiliser. The split 5% LSD is to be used when comparing split vs not split (for 33 and 67 % of standard rate N).

Compost rate (t/ha)	0	25	50	0	25	25 split	50	50 split	0	25	25 split	50	50 split	0	25	50	5% lsd 22 df	Split 5% lsd 14 df
N (% of standard rate)	0	0	0	33	33	33	33	33	67	67	67	67	67	100	100	100		
Earthworm populations (no/m^2)	211	133	117	88	141	ND	144	ND	144	197	ND	136	ND	91	66	152	121	-
Structural condition score	4.50	4.33	5.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.25	4.17	4.33	1.25	-
Drained upper limit (% v/v)	39.66	36.63	36.63	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	36.60	39.97	37.11	3.63	-
Aggregate stability (mm, MWD)	1.70	1.63	1.73	1.70	1.90	1.95	1.79	1.82	1.83	1.89	1.96	1.85	1.89	1.63	1.71	1.96	0.21	0.22
Aggregate stability (% >1 mm)	62.00	60.00	63.53	62.69	71.11	73.33	66.36	67.32	66.64	70.37	72.53	68.27	70.27	60.12	62.54	72.43	8.08	8.44
POM C (t/ha, 0–15 cm)	5.32	5.66	6.82	5.42	6.87	9.06	6.27	9.23	6.27	6.73	9.00	7.04	7.52	6.29	7.43	8.93	2.07	2.68
POM N (t/ha, 0–15 cm)	0.44	0.46	0.53	0.40	0.46	0.58	0.49	0.62	0.43	0.51	0.65	0.52	0.72	0.44	0.52	0.61	0.09	0.20
% organic C as POM C (0–15 cm)	12.05	12.53	14.87	12.00	13.87	18.87	14.24	17.94	13.55	13.68	16.90	14.85	14.87	13.45	15.45	16.98	3.83	5.90
% total N as POM N (0–15 cm)	12.28	12.71	14.06	10.93	11.66	14.76	13.53	14.95	11.47	12.73	15.11	13.46	16.61	11.69	13.14	14.37	2.60	4.92
Total N (%, 0–15 cm)	0.18	0.19	0.19	0.19	0.21	0.20	0.20	0.22	0.19	0.20	0.22	0.20	0.21	0.20	0.20	0.22	0.03	0.03
Total N (%, 15–30 cm)	0.14	0.16	0.15	0.15	0.17	0.15	0.15	0.16	0.15	0.15	0.17	0.15	0.16	0.16	0.16	0.17	0.03	0.03
Organic C (%, 0–15 cm)	2.24	2.36	2.28	2.33	2.59	2.48	2.35	2.66	2.33	2.51	2.69	2.43	2.50	2.39	2.43	2.67	0.35	0.32
Organic C (%, 15–30 cm)	1.63	1.85	1.79	1.76	2.12	1.70	1.80	1.85	1.78	1.75	2.03	1.81	1.77	1.88	1.85	1.96	0.41	0.39
C:N ratio (0–15 cm)	12.34	12.09	12.05	12.22	12.35	12.33	12.03	12.36	12.40	12.26	12.39	12.24	11.71	12.20	12.01	12.27	0.73	0.59
C:N ratio (15–30 cm)	10.09	10.48	10.52	10.40	10.94	10.32	10.40	10.37	10.51	10.37	10.84	10.50	10.12	10.43	10.28	10.08	0.77	0.57
pH	5.93	6.30	6.30	6.10	6.13	6.13	6.30	6.30	6.03	6.13	6.27	6.20	6.20	6.00	6.03	6.10	0.25	0.29
Olsen P (mg/L)	17.00	14.33	17.67	13.67	19.67	16.00	15.67	21.00	11.67	17.33	21.33	14.67	18.00	13.33	14.67	19.33	7.06	5.21
Potassium (me/100 g)	0.16	0.18	0.19	0.15	0.20	0.18	0.17	0.27	0.15	0.16	0.28	0.19	0.24	0.15	0.16	0.19	0.04	0.09
Calcium (me/100 g)	6.10	8.40	7.70	7.13	8.23	7.37	7.60	8.80	6.90	7.63	8.77	7.60	7.3	6.80	7.30	7.53	1.65	1.52
Magnesium (me/100 g)	0.33	0.45	0.51	0.39	0.50	0.50	0.48	0.70	0.35	0.46	0.60	0.52	0.63	0.33	0.42	0.52	0.09	0.14
Sodium (me/100 g)	0.13	0.16	0.17	0.13	0.15	0.14	0.18	0.15	0.13	0.13	0.20	0.13	0.19	0.12	0.13	0.12	0.03	0.03
CEC (me/100 g)	13.00	14.67	13.33	13.67	15.33	13.67	13.00	15.33	14.00	14.00	16.00	13.67	13.67	14.00	14.67	14.67	2.04	2.05
Potassium (QT)	2.67	3.00	3.33	2.67	3.33	3.33	3.33	5.00	2.67	3.00	5.00	3.33	4.33	2.67	2.67	3.33	0.74	1.60
Calcium (QT)	6.33	9.33	8.67	8.33	8.67	8.33	9.00	9.67	7.67	8.67	9.33	8.00	8.67	7.67	8.00	8.33	1.75	1.84
Magnesium (QT)	6.67	8.67	10.33	8.33	9.67	10.33	10.00	14.00	6.67	9.33	11.67	10.33	13.00	7.00	8.33	10.33	1.88	2.70
Sodium (QT)	5.33	6.33	7.33	5.67	5.67	5.67	7.33	6.00	5.33	5.33	8.00	5.00	8.00	4.67	5.33	4.67	1.23	1.47
PMN (kg N/ha, 0–15 cm)	91.21	84.80	96.02	84.61	90.69	101.2	87.78	98.87	80.18	89.24	85.27	92.43	85.79	78.67	79.39	88.36	15.78	16.64
Mineral N (kg/ha, 0–20 cm)	11.49	9.49	4.22	4.27	6.09	4.42	9.50	6.49	7.59	9.02	5.23	8.74	13.21	8.45	11.73	5.97	10.00	5.00
Mineral N (kg/ha, 20–40 cm)	3.01	6.67	1.62	0.50	0.89	3.18	4.58	2.80	4.16	5.87	3.25	3.31	3.29	6.47	5.18	2.58	10.00	5.00
Mineral N (kg/ha, 40–60 cm)	1.72	5.72	0.21	0.08	1.27	0.74	3.23	2.85	2.09	3.14	1.80	2.77	1.12	4.00	5.41	1.43	10.00	5.00
Mineral N (kg/ha, 60–90 cm)	2.11	8.58	0.96	0.03	1.98	2.35	7.33	1.60	5.04	2.69	3.72	6.25	2.81	6.80	7.31	2.92	10.00	5.00
Mineral N (kg/ha, 90–120 cm)	2.83	5.21	1.44	0.03	2.27	3.85	6.70	4.08	8.79	4.91	5.18	6.66	5.13	7.38	9.40	4.36	10.00	5.00
Mineral N (kg/ha, 120–150 cm)	4.94	5.34	3.77	2.55	3.53	9.09	8.97	6.73	11.68	10.58	9.17	9.86	11.51	13.53	18.24	18.31	10.00	5.00

ND = No data available
QT = MAF quicktest units

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Table 17: Treatment means with 5% LSD for each soil variate measured at the end of the pea crop (2012) at the arable crop in response to compost rate and N fertiliser. The split 5% LSD is to be used when comparing split vs not split (for 33 and 67 % of standard rate N).

Compost rate (t/ha)	0	25	50	0	25	25 split	50	50 split	0	25	25 split	50	50 split	0	25	50	5% lsd 22 df	Split 5% lsd 14 df
N (% of standard rate)	0	0	0	33	33	33	33	33	67	67	67	67	67	100	100	100		
Bulk density (g/cm^3, 0–15 cm)	1.31	1.32	1.38	1.34	1.30	1.34	1.29	1.30	1.30	1.33	1.32	1.27	1.30	1.32	1.37	1.30	0.06	0.07
Bulk density (g/cm^3, 15–30 cm)	1.40	1.31	1.36	1.39	1.33	1.39	1.40	1.43	1.38	1.38	1.41	1.43	1.45	1.37	1.37	1.38	0.09	0.07
Structural condition score	4.00	3.71	4.58	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.21	3.75	4.79	0.90	-
Drained upper limit (% v/v)	29.01	30.86	30.90	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	29.86	29.55	34.01	3.77	-
Aggregate stability (mm, MWD)	1.64	1.49	1.49	1.32	1.68	1.78	1.49	1.72	1.56	1.69	1.62	1.75	1.54	1.57	1.56	1.73	0.30	0.38
Aggregate stability (% >1 mm)	61.30	53.99	53.45	47.69	61.79	66.07	53.83	64.21	56.71	62.03	59.43	65.36	54.15	57.89	56.35	65.42	12.52	14.67
POM C (t/ha, 0–15 cm)	6.44	7.76	9.03	7.69	8.71	9.01	8.34	9.15	7.16	8.92	9.27	8.98	9.29	7.89	7.85	9.75	1.44	1.20
POM N (t/ha, 0–15 cm)	0.44	0.51	0.59	0.49	0.54	0.61	0.58	0.59	0.46	0.63	0.61	0.59	0.63	0.51	0.52	0.63	0.09	0.09
% organic C as POM C (0–15 cm)	14.53	16.81	19.21	16.12	17.28	17.90	18.22	18.70	15.94	17.94	17.98	19.73	19.91	16.33	15.93	19.68	2.0	1.74
% total N as POM N (0-15 cm)	12.03	13.32	15.03	12.82	13.18	14.75	15.07	14.41	12.75	15.10	14.40	15.79	15.98	13.02	12.64	15.01	1.72	1.61
Total N (%, 0–15 cm)	0.18	0.20	0.19	0.19	0.21	0.21	0.20	0.21	0.18	0.21	0.21	0.19	0.20	0.20	0.20	0.21	0.02	0.02
Total N (%, 15–30 cm)	0.15	0.16	0.15	0.15	0.17	0.15	0.15	0.16	0.15	0.16	0.16	0.16	0.15	0.17	0.16	0.17	0.03	0.03
Organic C (%, 0–15 cm)	2.25	2.33	2.28	2.37	2.59	2.51	2.38	2.51	2.30	2.50	2.60	2.39	2.40	2.46	2.41	2.54	0.29	0.25
Organic C (%, 15–30 cm)	1.75	1.96	1.71	1.79	2.06	1.75	1.80	1.84	1.83	1.79	1.96	1.85	1.78	1.94	1.84	1.98	0.40	0.41
C:N ratio (0–15 cm)	12.20	11.79	11.96	12.49	12.24	12.18	11.79	11.96	12.38	11.89	12.16	12.21	11.88	12.13	12.07	11.89	0.72	0.59
C:N ratio (15–30 cm)	10.29	10.81	10.38	10.26	10.46	10.41	10.67	10.41	10.50	10.18	10.43	10.43	10.15	10.15	10.29	10.45	0.89	0.94
pH	5.67	6.00	6.07	5.83	5.90	5.90	5.97	5.90	5.70	5.90	6.03	5.83	5.97	5.67	5.83	5.80	0.23	0.20
Olsen P (mg/L)	18.00	14.67	15.00	17.00	20.33	16.33	15.00	16.00	13.00	18.67	18.67	14.33	16.67	12.67	12.00	16.67	4.70	5.19
Potassium (me/100 g)	0.16	0.19	0.21	0.17	0.22	0.21	0.23	0.23	0.15	0.18	0.24	0.21	0.26	0.17	0.16	0.20	0.03	0.08
Calcium (me/100 g)	6.10	7.33	7.33	6.93	7.33	6.97	7.77	7.50	6.23	7.03	7.47	6.83	7.10	6.33	6.83	7.07	0.82	1.21
Magnesium (me/100 g)	0.33	0.43	0.49	0.38	0.45	0.49	0.50	0.53	0.33	0.40	0.50	0.48	0.55	0.32	0.37	0.47	0.06	0.13
Sodium (me/100 g)	0.16	0.15	0.19	0.15	0.15	0.14	0.18	0.16	0.14	0.15	0.18	0.16	0.18	0.16	0.15	0.15	0.02	0.03
CEC (me/100 g)	12.33	13.00	12.67	13.33	13.67	12.67	13.67	14.00	12.67	13.33	13.67	13.00	13.00	13.00	13.00	14.00	1.34	1.96
Potassium (QT)	3.00	3.33	4.00	3.00	4.00	4.00	4.33	4.33	3.00	3.33	4.67	4.00	5.33	3.33	3.33	3.67	0.76	1.60
Calcium (QT)	7.00	8.33	8.67	7.67	8.67	8.00	9.00	8.67	7.00	8.00	8.67	7.67	8.67	7.33	7.67	8.33	1.03	1.15
Magnesium (QT)	7.00	8.67	10.33	8.00	9.33	10.67	10.33	11.00	6.67	8.00	10.33	10.00	12.00	6.33	7.67	9.67	1.24	2.31
Sodium (QT)	6.67	6.33	8.33	6.33	6.33	6.00	7.67	7.00	6.00	6.33	8.00	6.67	8.00	6.67	6.67	6.67	1.06	1.01
PMN (kg N/ha, 0–15 cm)	66.90	57.09	65.65	56.67	59.83	66.62	57.58	67.15	53.70	54.67	53.99	66.39	52.56	50.55	56.60	52.40	16.49	20.48

ND = No data available
QT = MAF quicktest units

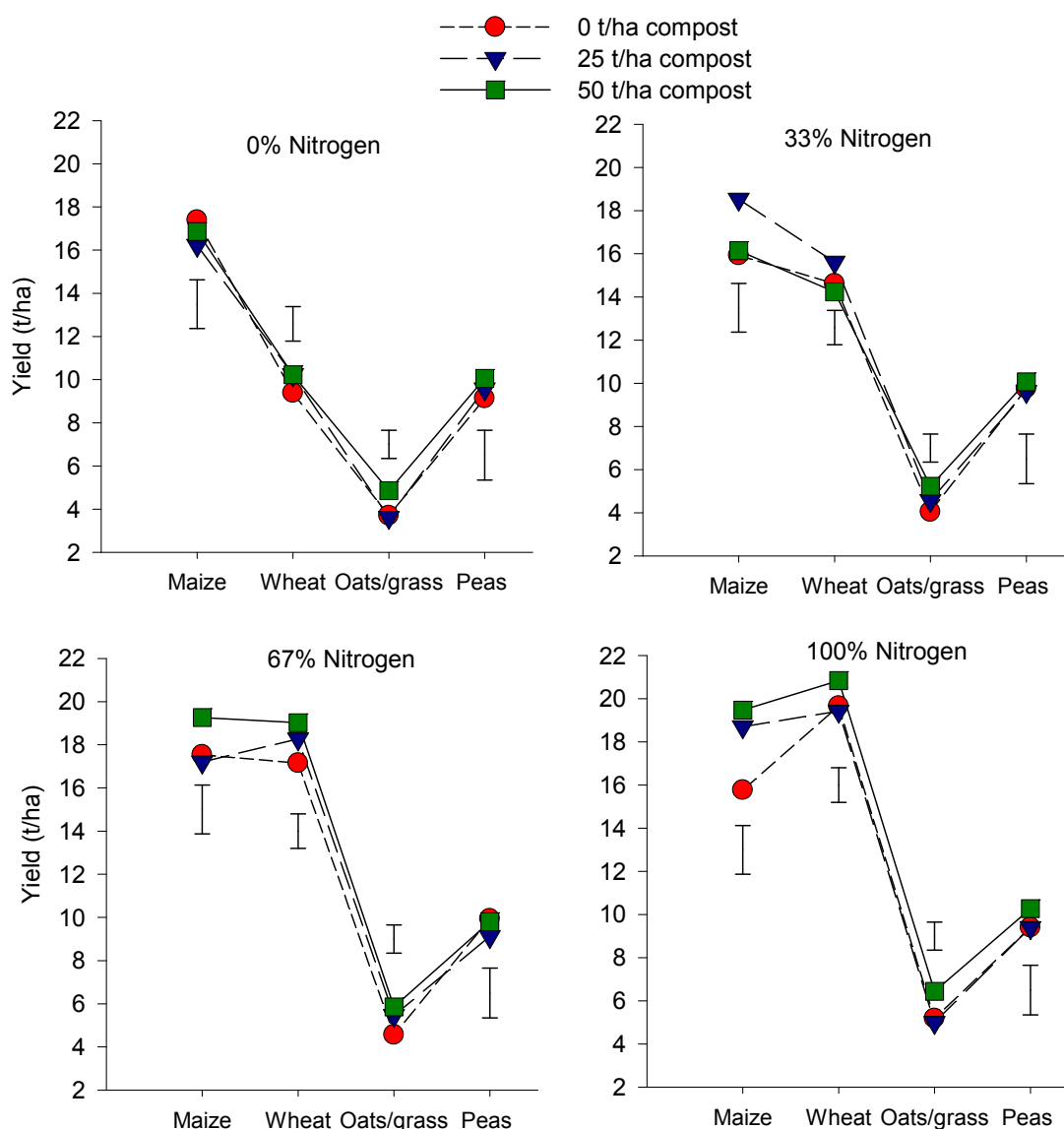## 3.1.5   Crop yield from one-off applications of compost

Figure 22: Effects of compost and nitrogen treatments on total crop yield (t/ha) at the arable crop trial from 2010 to 2012. Bars represent 5% LSD with approx. 32 df.

First crop – Maize

Overall, there were significant effects of the compost and fertiliser N treatments and their interaction on the dry matter yield of silage maize, but only where compost and fertiliser were applied together (Figure 22). Additions of compost at the start of the arable cropping rotation increased the dry matter yield of silage maize compared with the control. Where compost was added, the dry matter yield of maize silage increased by about 25 kg maize silage DM per kg of available N. At this stage of the trial there was, however, no difference in yield recorded from the two different compost rates (i.e. 25 or 50 t/ha, P = 0.699). An interesting finding was that the response to available N was affected by the presence of compost (P = 0.078) with significantly more N being taken up by the plants where compost was applied (P = 0.047). The significantly lower response to available N in the absence of compost (represented by the lack of slope in the 'without compost' line in Figure 23), suggests that there was something in the compost

which improved the crops ability to utilise available N. The mechanisms for this remain unclear given other nutrients important to the crop were not limiting. The effect was only apparent where compost and inorganic fertiliser were applied together. Where compost was applied in the absence of N fertiliser, yields did not differ from the control. These findings support those of Keeling (2003) and Sikora and Azid (1993) where benefits of compost were only apparent when applied alongside mineral N fertilisers.
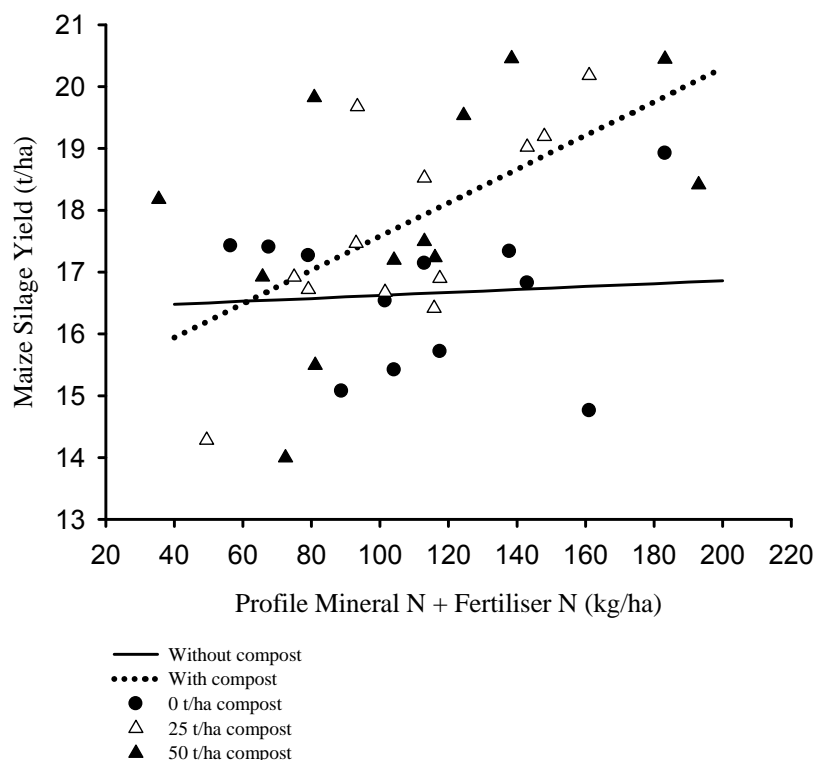
Figure 23: Effects of compost treatment and N (soil profile mineral N to 1.5 m depth, plus fertiliser N) on silage-maize dry matter yield (t/ha) at the arable crop trial (2009-2010).

Second crop – Wheat

Although on average the yield of the second crop (i.e. wheat) did increase with compost, the differences were not significant (P = 0.382, Figure 22). Unlike in the maize crop, compost did not effect the crops ability to access avialable N as there was strong evidence (P < 0.001) that the wheat yield responded to soil available N, regardless of whether compost had been applied.

Third crop – Oats/Ryegrass

Yield results from the oat/ryegrass crop were significantly higher for 50 t/ha compost treatment (P = 0.003, Figure 22). This was the first crop where there was any significant compost rate-induced yield differences, suggesting that it takes time before the additional units of compost become beneficial. The incubation study (Section 3.7) showed that most of the C and N from the compost applied at this site was in resistant pools that were slow to decompose. Significant yield differences occurring in the 50 t/ha treatment may be due to nutrients becoming available to the crop as a consequence of microbially activated decomposition of these more resistant fractions.

Fourth crop – Peas

Peas were included as a crop in the arable rotation to represent standard practise in Canterbury. Research throughout New Zealand has confirmed that peas do not respond to the application of N, P of K fertilisers (FAR 2002). Yields for the fourth and final crop (peas) at the arable crop trial support this as pea yields were not affected by compost rate ($P = 0.467$) or fertiliser N ($P = 0.612$), Figure 24. Available N still present at the end of this fourth crop (see Section 3.3.2) suggests that there is reason to conclude that subsequent crops may have still benefited from the compost applied 3 years previously.
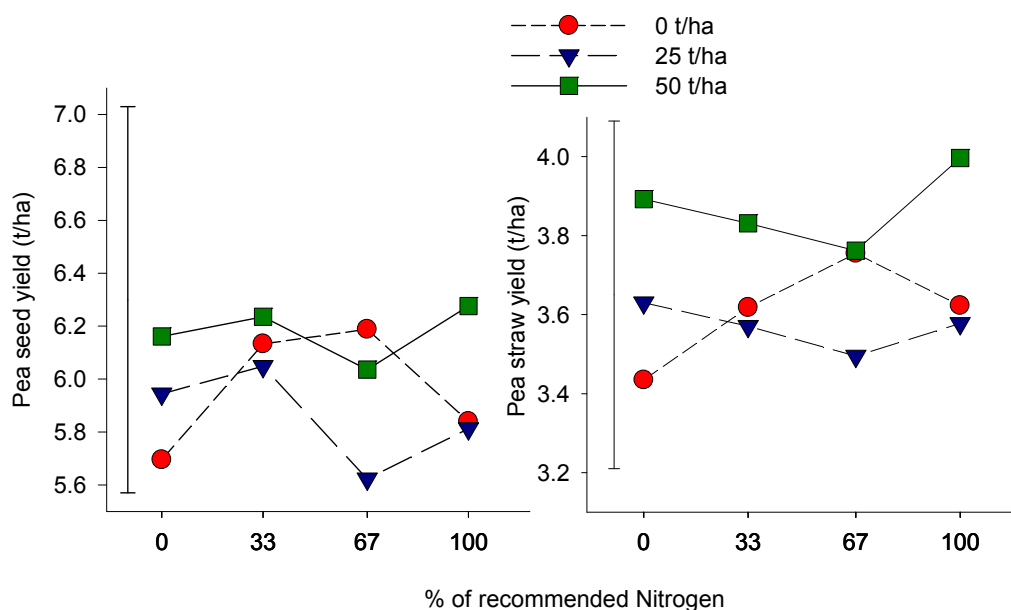
Figure 24: Effects of compost and nitrogen treatments on pea seed and pea straw yield at the arable crop trial (2011-2012). Bars represent 5% LSD with 28 df.

These results suggest that yields do not immediately benefit when compost is first applied in the absence of fertiliser N. With time, where 50 t/ha compost was applied in the absence of N fertiliser, there were improvements in yield compared with the control. These results support the slow release potential of compost nutrients and that 50 t/ha will have more of a long-lasting effect on yields than 25 t/ha in an arable cropping rotation.

3.1.6   N uptake from one-off applications of compost

Overall fertiliser treatment had a strong effect on crop N uptake ($P < 0.001$), which increased with increasing fertiliser rates for all crops except peas ($P = 0.969$). This reinforces results discussed in Section 3.3.1 that the peas did not respond to available N. There is some evidence that the compost being applied led to greater N uptake; this was particularly evident in the oat and grass crops ($P = 0.012$ and $P = 0.052$ respectively), with the 50 t/ha rate of compost having the greatest effect where the full rate of fertiliser was applied (Figure 25). Where no compost was applied there were no relative differences between the total N taken up by all crops between the 67 and 100% fertiliser N rates (739 and 737 kg/ha respectively). However, when compost was applied total N taken up by the crop between the 67 and 100% fertiliser N rates went up from 760 to 811 kg/ha. These results support the finding that compost increases utilisation of available N.
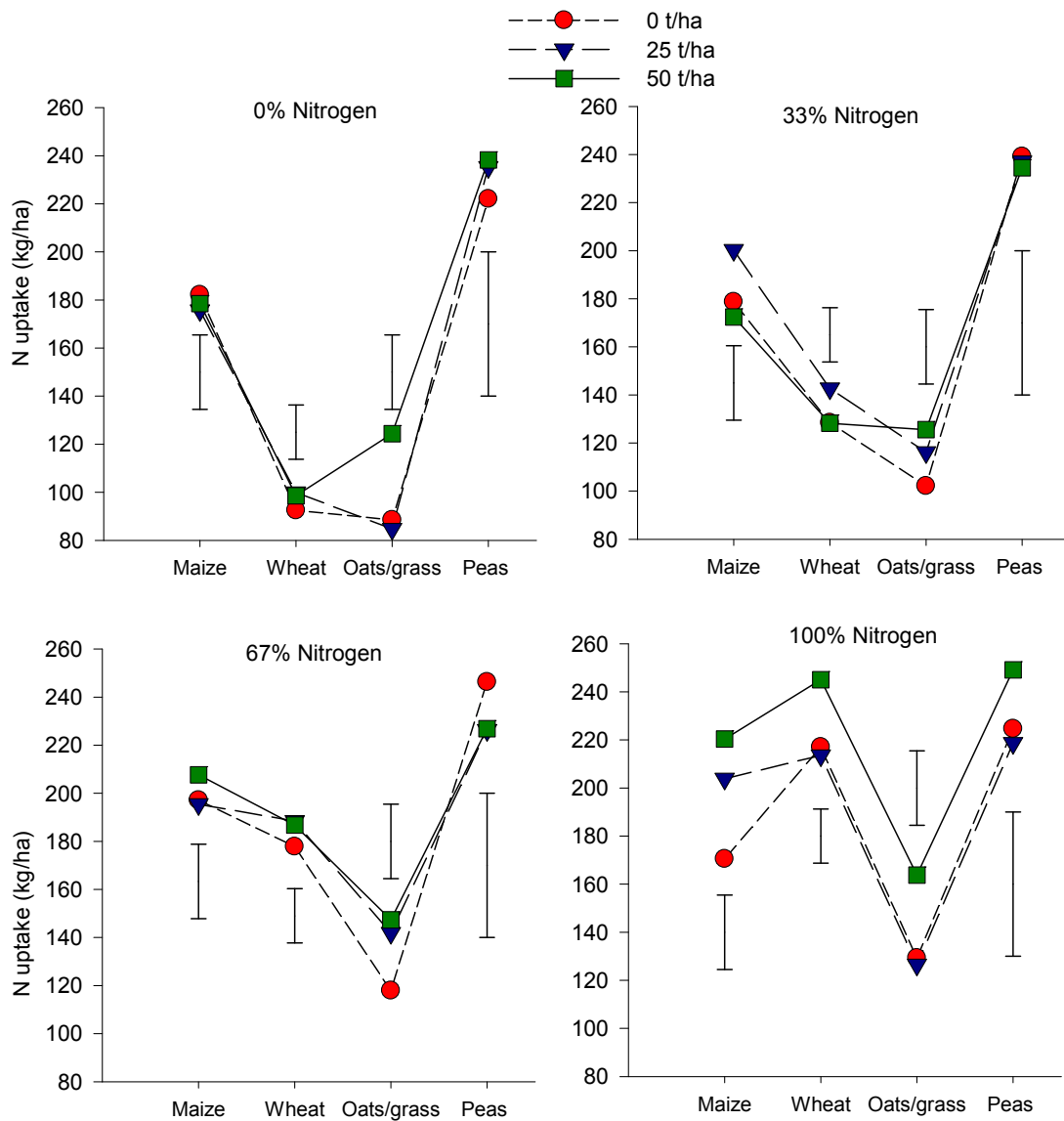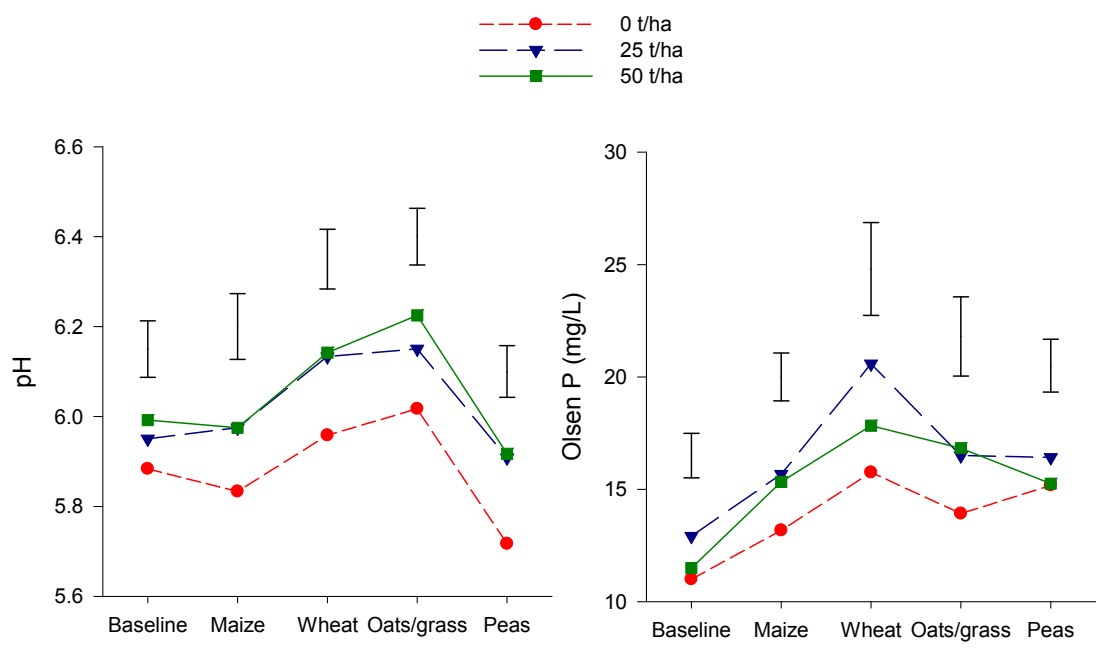
Figure 25: Effects of compost and nitrogen treatments on N uptake (kg/ha) at the arable crop trial (2010-2012). Bars represent 5% LSD with approx. 32 df.

3.1.7   Soil chemical fertility from one-off applications of compost

There is evidence that the one-off application of compost in 2009 had an effect on quicktest potassium, calcium, magnesium and sodium, with P values ranging from P = 0.004 to <0.001; P < 0.001 to 0.072; P <0.001; P = 0.002 to 0.059, respectively, with concentrations of nutrients increasing where compost had been applied (Figure 26). In contrast, the N fertiliser treatments did not influence the level of these post-harvest quicktest soil measurements with the exception of Na, especially in the last two crops (P < 0.001 and P = 0.099 respectively). K quicktest levels diminished a lot more rapidly than Mg levels most likely due to high crop demands, especially for the maize silage crop.
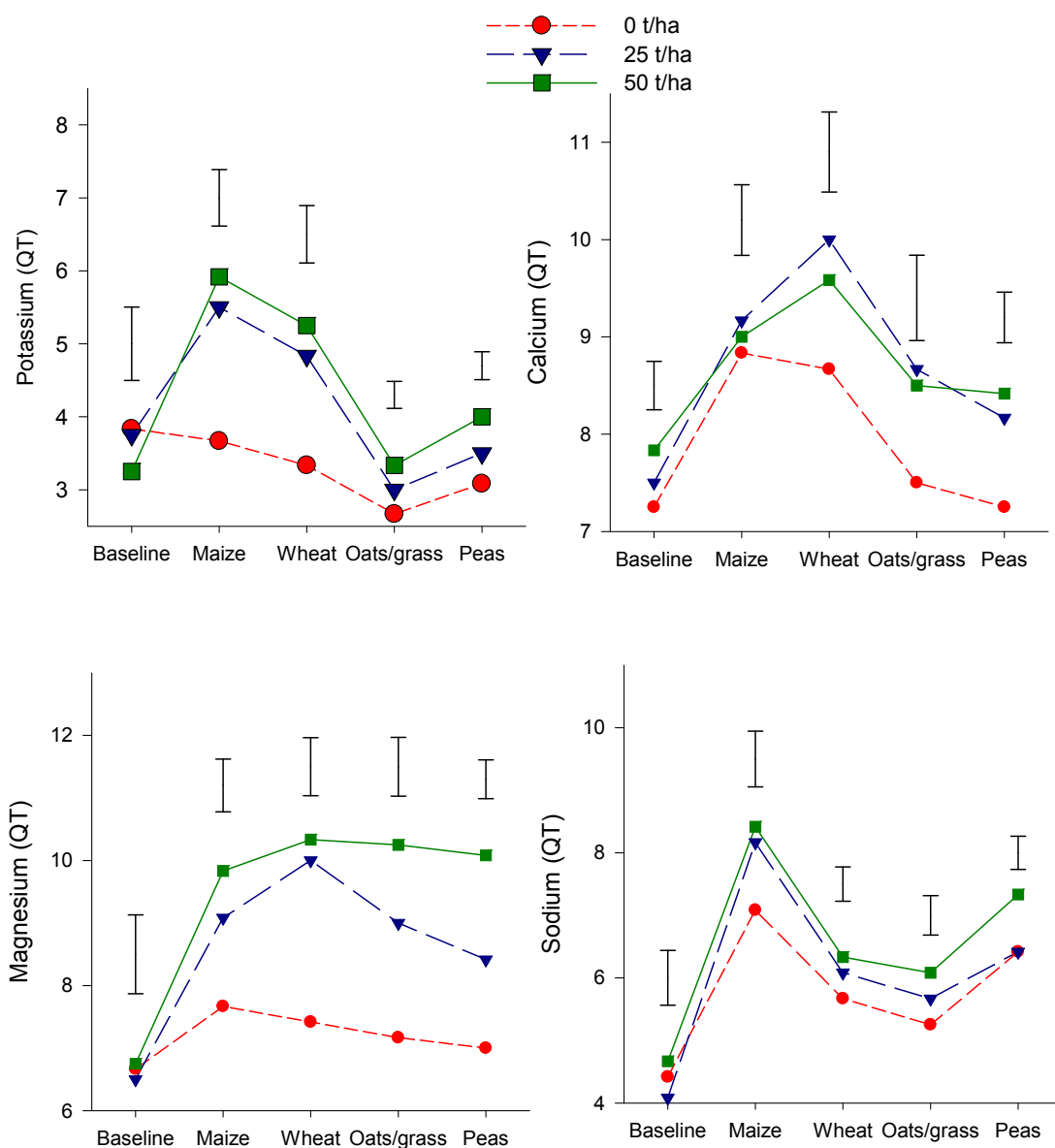
Figure 26: Effects of compost treatment on soil quicktest K, Ca, Mg and Na (0–15 cm) at the arable crop trial (2009-2012). Bars represent 5% LSD with 22 df.

Applying compost increased soil pH values over the duration of the trial (P = 0.002–0.014, Figure 27). There was a drop in pH after the peas, which is expected from a legume, but overall the pH remained higher where compost had been applied in 2009. There is also some evidence of a compost effect on soil Olsen P; values being higher where compost was applied than where it was not (P = 0.048–0.48). On average the one-off application of compost added in 2009 led to a 3 unit increase in Olsen P values (Figure 27). This equates to an extra 15 kg P/ha for each subsequent crop which would mean a saving of $150/ha per crop.
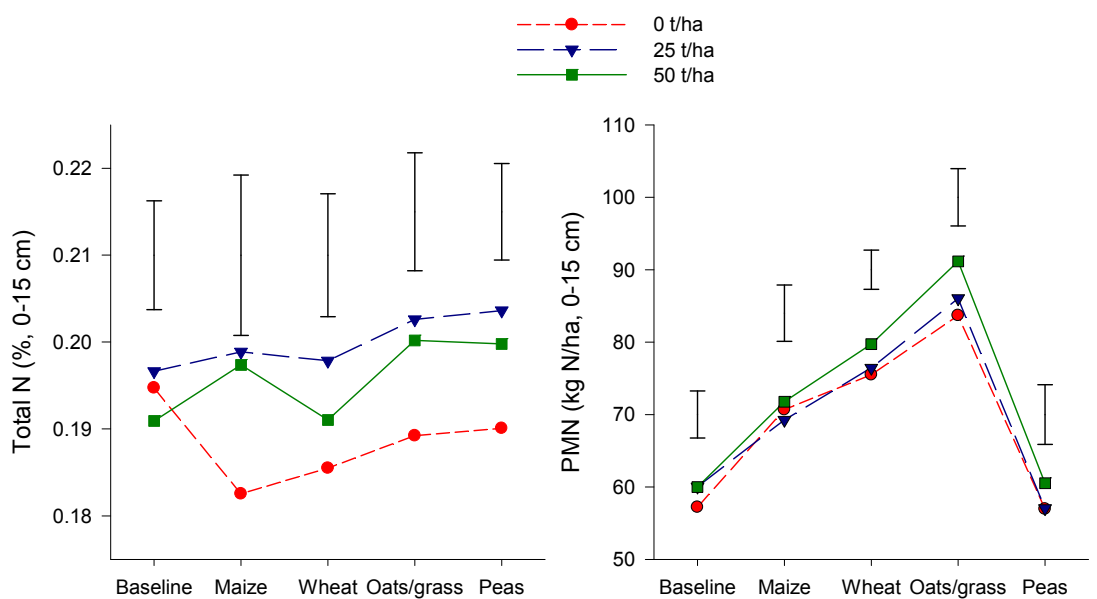
Figure 27: Effects of compost and nitrogen treatments on soil pH and Olsen P at the arable crop trial (2009-2012). Bars represent 5% LSD with 22 df.

Nitrogen is an essential component of the proteins that builds all living matter including plant tissue and so is one of the most important nutrients for plant development. There was evidence that compost had an effect on increasing soil total N compared with where no compost had been applied, especially at the end of the trial after the pea crop (P = 0.064). In terms of soil available N (represented by potentially mineralisable N, Figure 28), although there were trends for greater available soil N where compost had been applied, the variability was high and the differences were not significant. This variability was also apparent with nitrogen fertiliser treatments effect on soil available N and P values ranged from P = 0.219 to 0.899.

Figure 28: Effects of compost and nitrogen treatments on total soil N and potentially mineralisable N at the arable crop trial (2009-2012). Bars represent 5% LSD with 22 df.

3.1.8   Deep soil mineral N and nitrate leaching from one-off applications of compost

The results of our water balance calculations indicated that there was no measureable drainage of water between sowing (November 2009) and harvest (April 2010) of the maize silage crop, and therefore there was no nitrate leached from the treatments during this period. However, during the subsequent wheat crop (May–July 2010) there were numerous drainage events, each followed by the collection of soil solution samples at a depth of 1.5 m to determine the nitrate concentration and to calculate leaching losses. Further soil solution sampling took place after drainage events during the winter of 2011 in the oats and grass crop.

Cumulative nitrate leached over the duration of the trial is presented in Figure 29 (note that solution sampling tubes were only installed in selected treatments). Overall leaching losses for the duration of the trial were low with no strong treatment effects. There was no evidence that the nitrate leached from compost treated plots was more than that leached from plots with no applied compost; if anything there was a trend for less leaching where compost had been applied ($P = 0.195$, Figure 29). Nitrate leaching increased with available N ($P = 0.063$) and there were trends for more nitrate leaching the greater the N fertiliser rate applied, although these differences were not significant ($P = 0.156$, Figure 29).

Findings in the literature (e.g. Leclerc et al. 1995) report higher nitrate leaching losses under crops receiving mineral NPK fertiliser compared with compost treatments. Findings from this study suggest that as additions of compost do not lead to increased nitrate leaching there may be potential to reduce total N leached if compost applications result in offsets to N fertiliser applications.
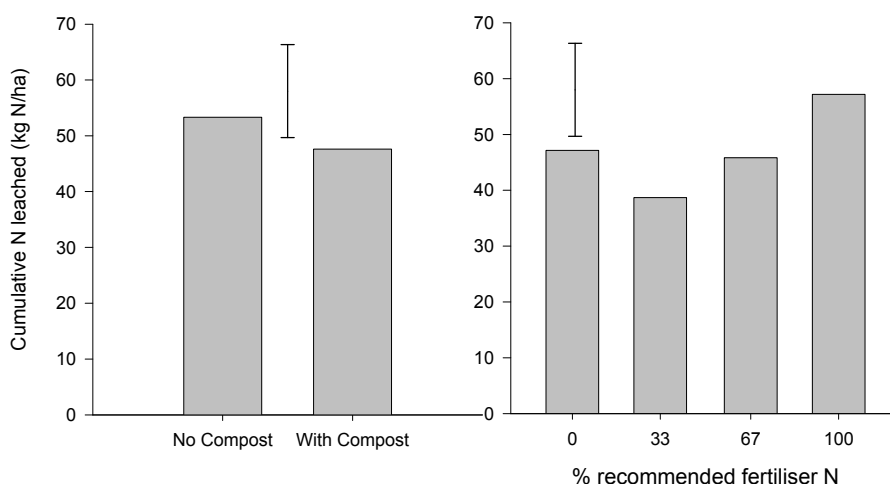

Figure 29: Effects of compost and N treatment on cumulative N leached (kg N/ha) at the arable crop trial (2010). Bars represent 5% LSD with 16 df.

Soil mineral N represents nitrogen that is available to be either taken up by the crop or leached from the system as nitrate. Figures 30 and 31 show how soil mineral N changes down the profile before and after winter 2010 and 2011 for four treatment combinations. In both years overall there is less soil N down the profile in spring than autumn ($P < 0.001$) due to crop uptake and N leaching. Applying compost did not have any effect on soil profile mineral N over the duration of the trial ($P = 0.901$). N fertiliser did have a strong effect on soil profile mineral N but this was only evident at depth ($P = 0.003$). As can be seen in Figure 31 there is more N available for leaching at depth the higher the fertiliser N rate, which may explain the trend of higher nitrate leaching with the higher N fertiliser rates (Figure 29).
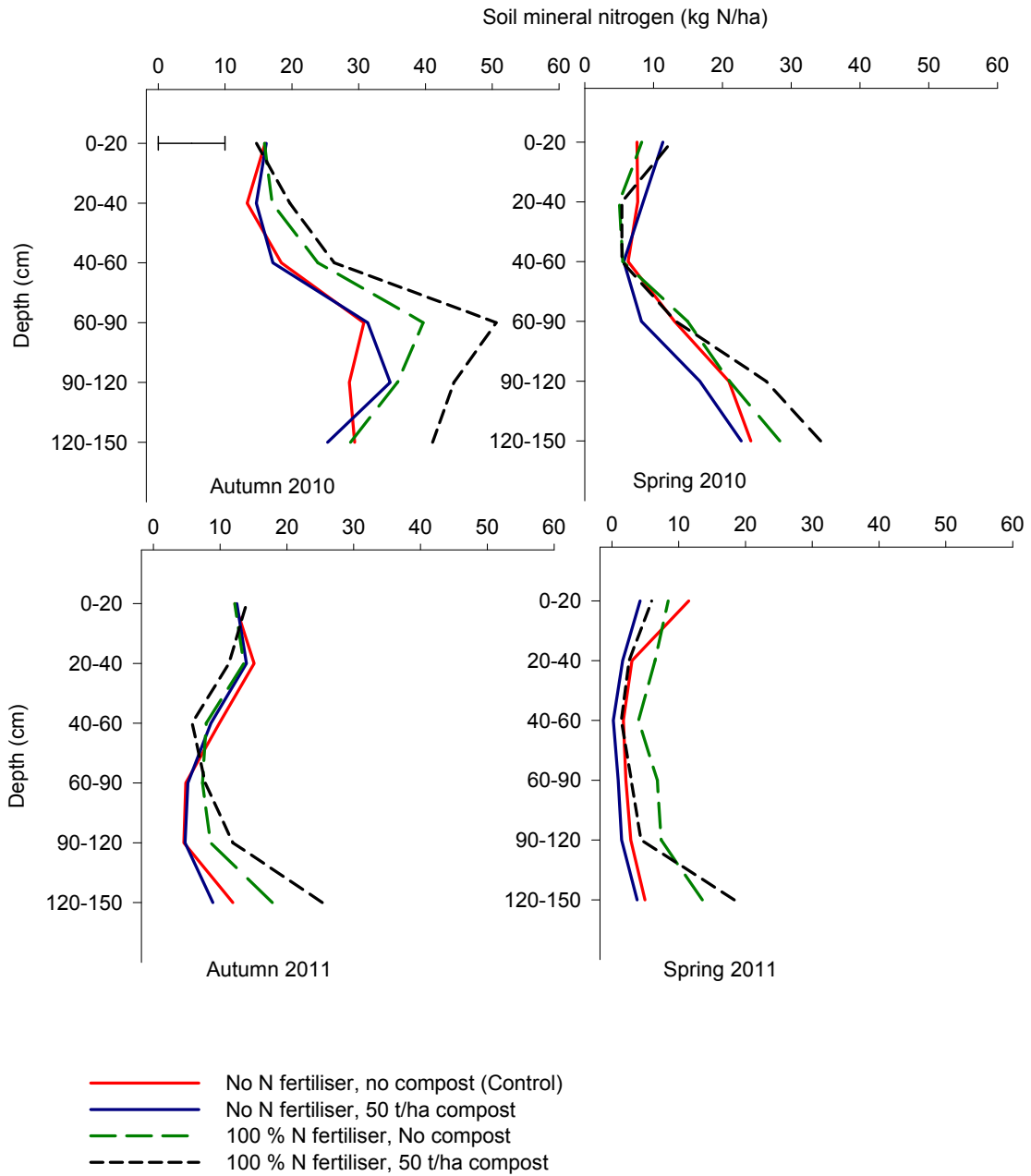
Figure 30: Effects of the compost (0 vs 50 t/ha) and N fertiliser (0 vs 100% of recommended rates) treatment combinations on soil mineral N levels (kg N/ha) in the soil profile of the arable crop trial at the beginning and end of winter, 2010 and 2011. Bar represent 5% LSD with 16 df.
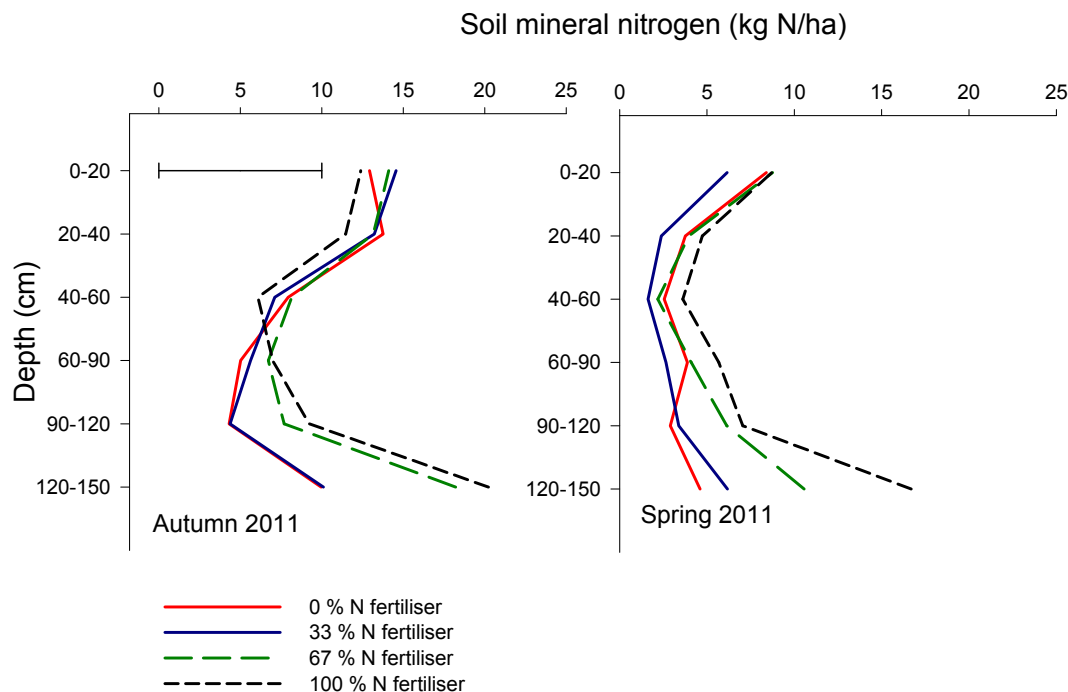
Figure 31: Effects of fertiliser N treatments on soil mineral N (kg N/ha) at the beginning and end of winter, 2011, at the arable crop trial. Bar represents 5% LSD with 16 df.

3.1.9 Soil physical condition from one-off applications of compost

It is well known that grass pasture and fine root crops (e.g. grass seed crops, barley, triticale) return large amounts of organic matter to the soil. Additions of compost can also contribute to improving organic matter levels (Sullivan et al. 2002, 2003). There is some evidence that the one-off application of compost in 2009 had an effect on soil organic C % in the 0–15 cm depth over the duration of the trial (P = 0.111–0.307). The increases in organic C observed are in line with what you would expect based on the rates of compost applied and the amount of organic matter in the compost (Table 4). Whether or not these improvements in SOM carry over to improving soil quality parameters varies depending on a number of factors such as the quality of the compost and how frequently it is applied. Literature suggests that sustained applications of compost are required before soil quality parameters such as bulk density and aggregate stability improve. There was little evidence to suggest that compost applied in 2009 at the arable crop trial had any effect on bulk density, with P values ranging from P = 0.151 to 0.746. There was some indication at the end of the trial of higher drained upper limit (DUL) for the 50 t/ha compost rate (P = 0.073, Figure 32) but the reverse was true for the previous crop. There was, however, a trend for improved aggregate stability with compost additions which was most apparent after the wheat and oat/grass crops (P = 0.064, Figure 32). Although there were no apparent compost-induced improvements in the soil condition score (SCS) measurements for the 25 t/ha rate of compost, there was some evidence that the 50 t/ha compost rate improved the SCS and this was most apparent after the wheat (P = 0.023, Figure 32). Soil structural condition score and aggregate stability are two important indicators of soil structural health as soils with high aggregate stability are better able to withstand the impacts of regular cultivation and rapid wetting of dry soil. Aggregates with low stability are more prone to dispersion by wind and water. These results support the idea that sustained applications of compost are required before soil quality can be expected to improve but the aggregate stability and SCS trends measured over the duration of this trial suggest that soil quality improvements are likely.
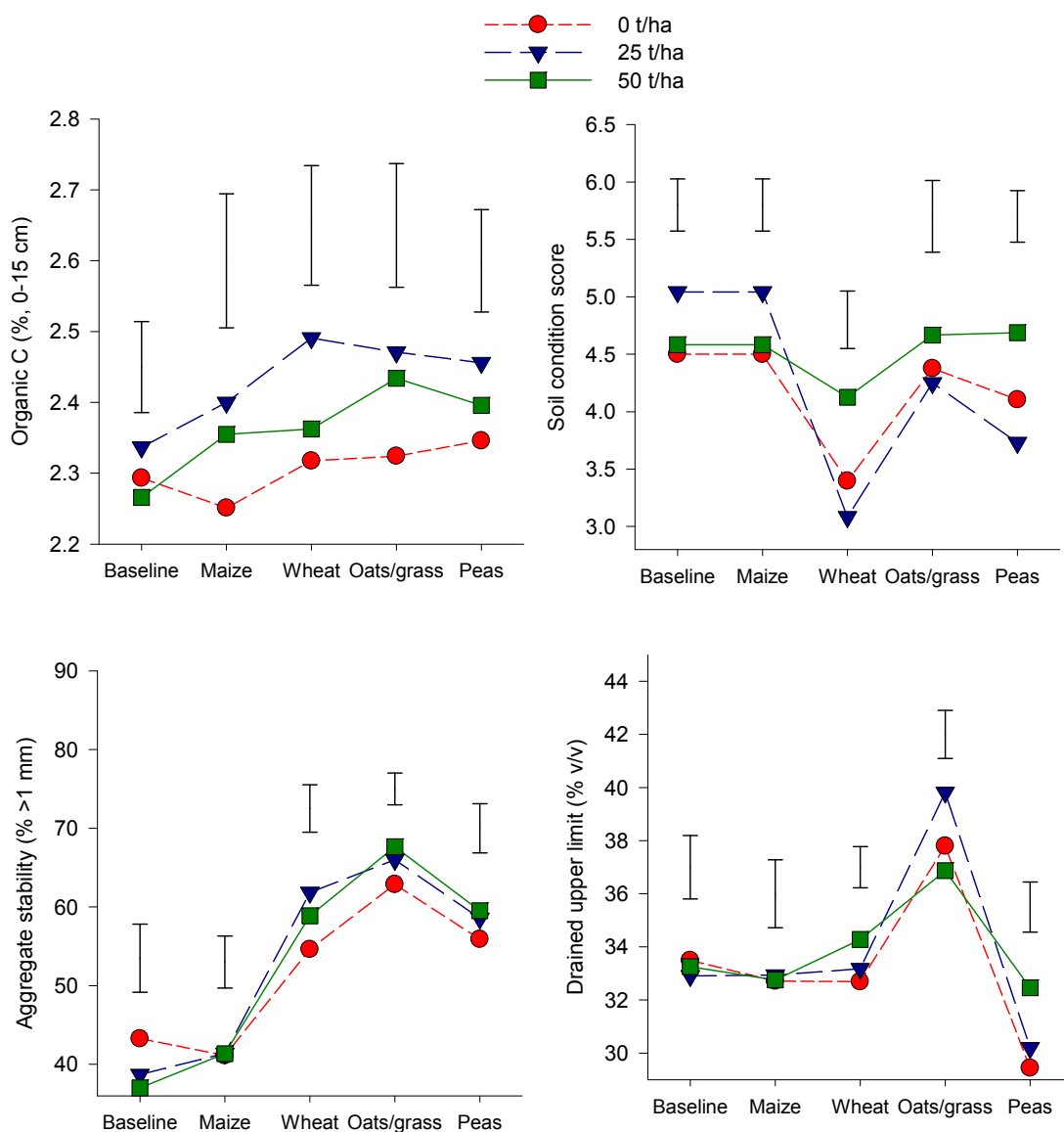
Figure 32: Effects of compost on soil organic C, soil condition score, aggregate stability and drained upper limit at the arable crop trial (2009 to 2012). Bars represent 5% LSD with 22 df.

3.1.10   Particulate Organic Matter (POM) from one-off applications of compost

POM generally consists of fine root fragments and other organic debris and plant material. This organic matter pool is important for SOM turnover because it serves as a readily decomposable substrate for soil micro-organisms and as a short-term reservoir for plant nutrients (Mrabet et al. 2001). POM pools naturally fluctuate depending on the stage of the arable rotation. As can be seen in Figure 33 there was a significant decrease in POM between baseline 2009 and the wheat crop harvested in 2011, after which it started to increase again. Figure 33 also shows that there is some evidence that the compost applied in 2009 had a effect on the % of POM C of total organic matter ($P = 0.113$) in 2011. As the compost decomposed further, differences between available nutrients, as measured by POM, continued to increase after the oats/grass crop ($P = 0.044$) and even more strongly at the end of the trial ($P < 0.001$) with the 50 t/ha compost rate resulting in the greatest % of POM C. Similarly, % total N as POM only increases as a result of applying compost after the oats/grass and peas crop towards the end of the trial ($P < 0.001$, Figure 33).

Among other things, POM is correlated with potentially mineralisable N and these results suggest there are fluctuations between the different pools of organic matter, explaining why the oat/grass crop was still able to benefit from compost application made well over a year earlier. Unlike at the forage crop trial where POM-N was significantly higher where compost had been applied for the first two crops after application, at the arable crop trial it was not until the compost had decomposed over time that there were measurable differences. These results support the possibility that there may be compost-related yield enhancements in subsequent crops.
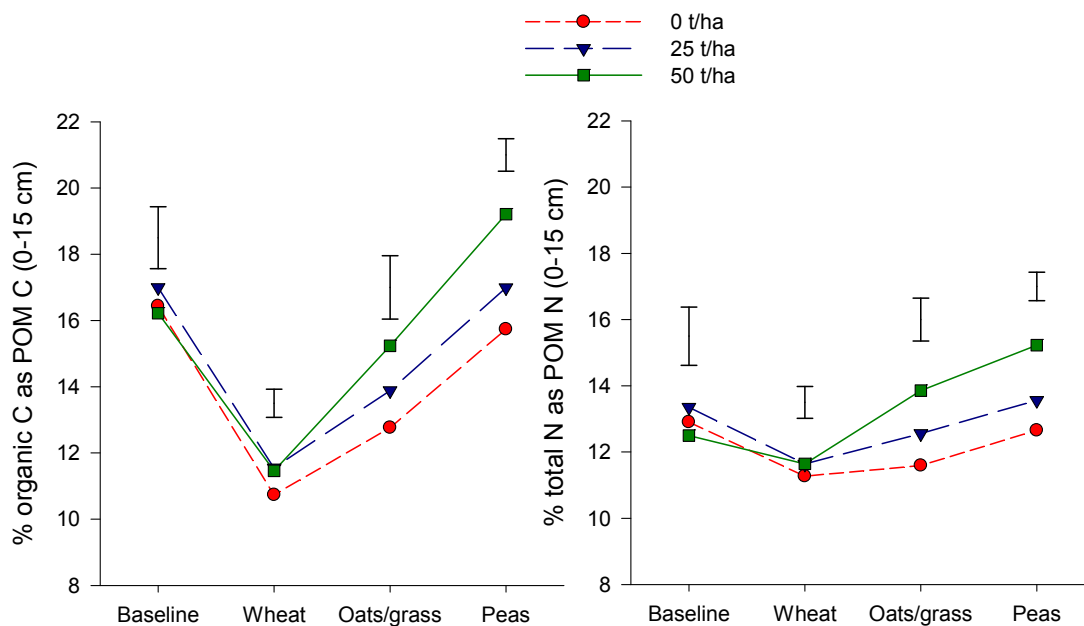
Figure 33: Effects of compost rate on the percentage of POM C from the total soil organic C pool and POM N from the soil total N pool (0–15 cm) at the arable crop trial (2009-2012). Bars represent 5% LSD with 22 df.

3.1.11   Crop yields from split applications of compost

Split applications of 25 t/ha and 50 t/ha over 3 years (8 and 17 t/ha per year, respectively) were only applied to half of the N treatments (33% and 67% of recommended N) and therefore the split compost analysis excludes 0% and 100% of recommended N. Some graphs include standard practise (100% recommended fertiliser N and no compost) for comparative purposes.

After the maize crop (when only 1 of the 3 split applications had been applied) there was an opportunity to look at how small application of 8 and 17t/ha compost compare to the 25 and 50 t/ha rates. While yield was higher where compost was applied (P = 0.026), compared with where 33% and 67% of recommended N had been applied in the absence of compost, there was no effect of compost rate (P = 0.933, Figure 34). In other words, yields for the first crop (maize) were the same, regardless of whether 8, 17, 25 or 50 t/ha of compost was applied.
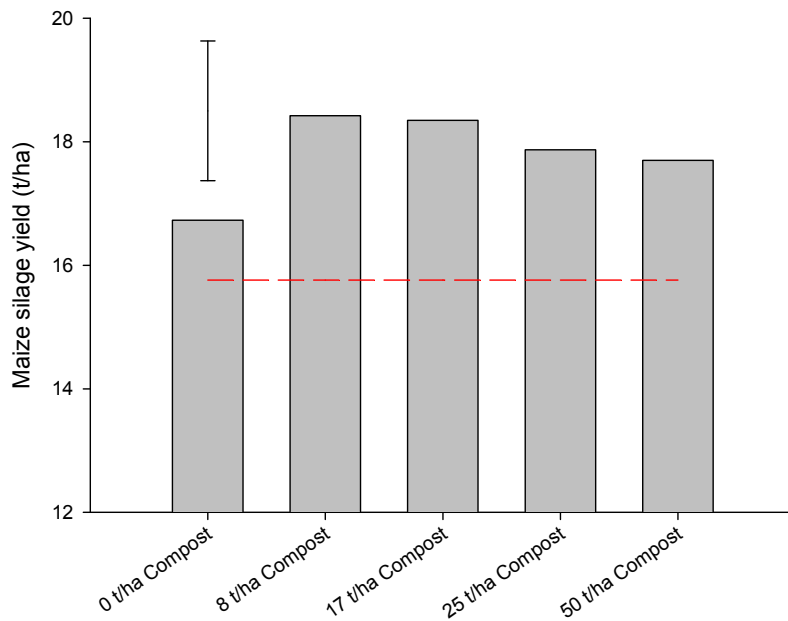
Figure 34: Effects of applying 0, 8, 17, 25, 50 t/ha compost on the first crop (maize) at the arable crop trial (2009-2010). Red dashed line represents standard practice. Bar represents 5% LSD with 32 df.

At the forage crop trial adding a small application of compost (12.5 t/ha) did not have any effect on soil parameters such as soil carbon %, POM levels, Olsen P and quicktest K. In contrast, at the arable crop trial, applying 8 and 17 t/ha compost (the first of the split applications) did result in responses with increases similar to the 25 and 50 /ha rate (Figures 35 and 36). Although there is a lack of difference between the 8, 17, 25 and 50 t/ha rates (or in some cases there were greater elevations with the smaller rates e.g. soil organic C; Figure 35), it is likely that if these rates were compared over time (as one-off applications) treatment differences would result in subsequent crops. This would be due to the higher compost rates releasing nutrients from a greater pool. This could not be validated in this trial as the 8 and 17 t/ha rates where reapplied annually for the next two years to make up the split treatment.
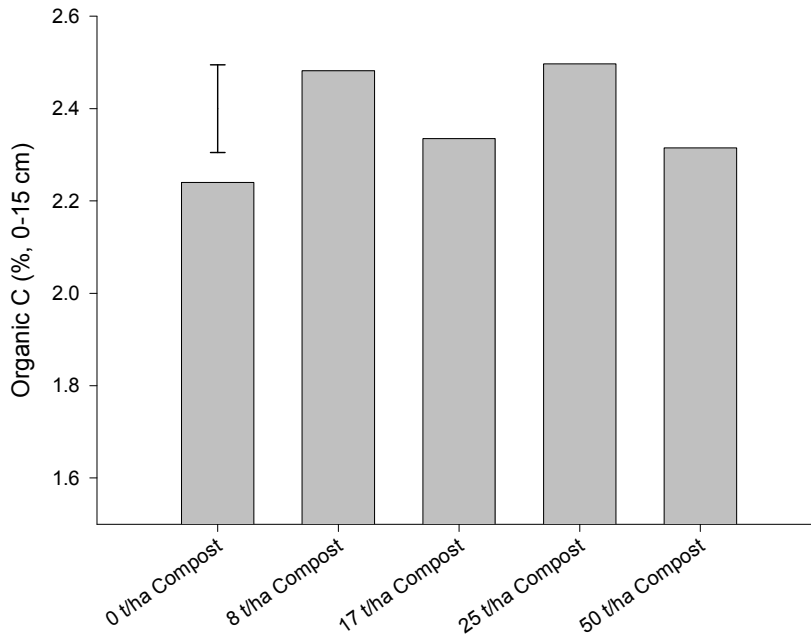
Figure 35: Effects of applying 0, 8, 17, 25, 50 t/ha compost on soil organic C and % of POM C from the total soil organic C pool at the arable crop trial (2009-2010). Bars represent 5% LSD with 30 df.
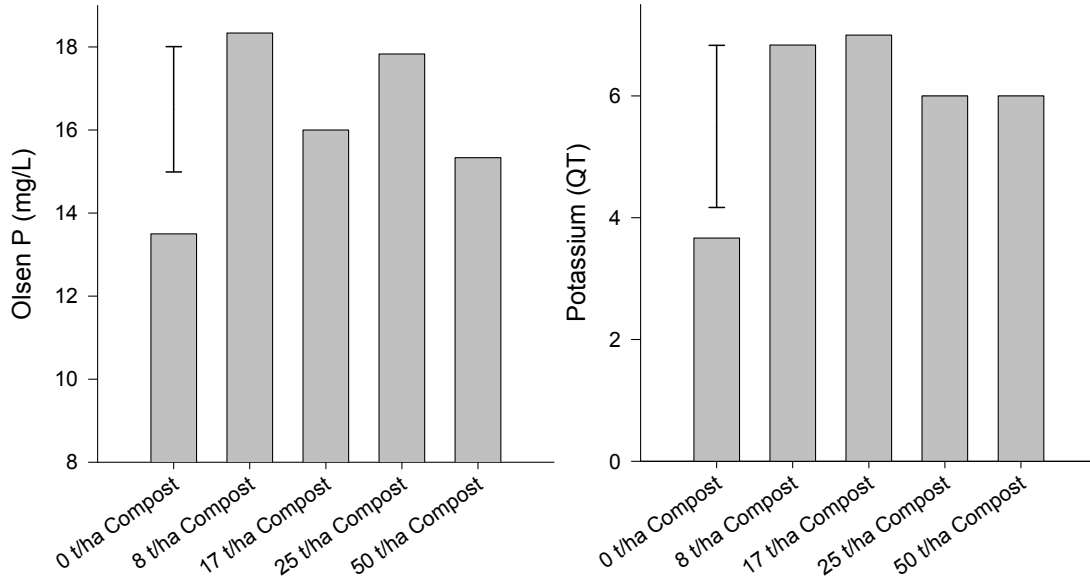

Figure 36: Effects of applying 0, 8, 17, 25, 50 t/ha compost on soil Olsen P and quicktest potassium at the arable crop trial (2009-2010). Bars represent 5% LSD with 32 df.

By the end of the trial after all three split applications had been applied cumulative yields were greater where the 25 and 50 t/ha compost rates had been applied as split applications than a single one-off application (Figure 37). A similar trend can be seen with N uptake as more N was taken up where the 25 and 50 t/ha compost rates were split over the 3 years (Figure 37).
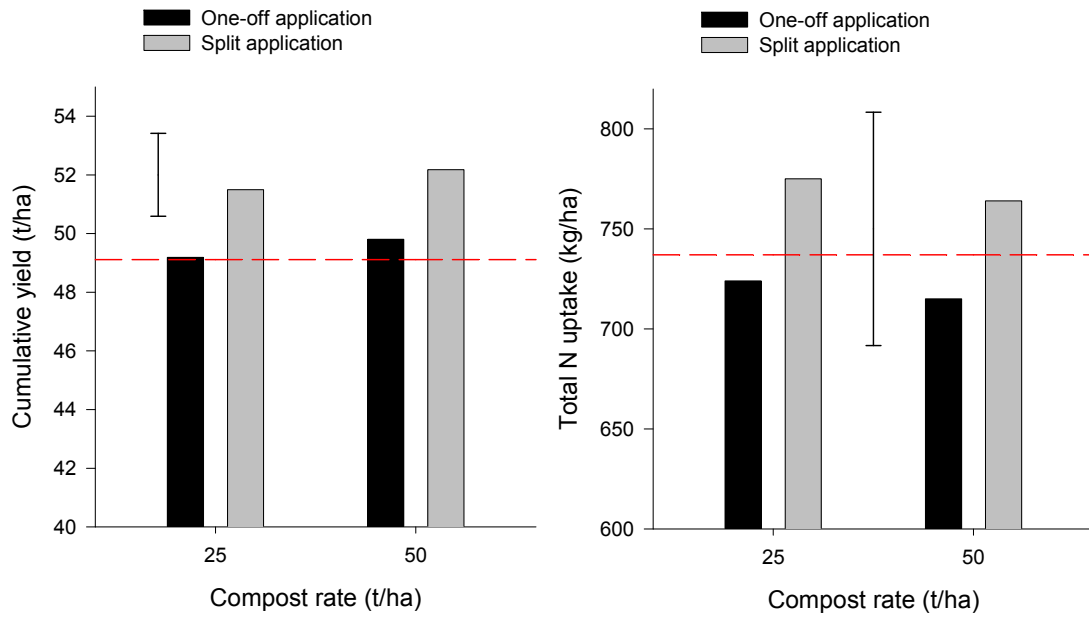
Figure 37: Effects of applying 25 and 50 t/ha as one-off or split applications on cumulative yield and total N uptake at the arable crop trial (2009-2012). Red dashed line represents standard practice. Bars represent 5% LSD with 27 df and 22 df respectively.

Similarly, after all three split applications of compost had been applied there were greater total soil K and Mg values when the compost was applied as split applications compared with one-off applications (Figure 38). Figure 38 also shows that regardless of whether compost was applied as one-off or split applications, nutrient levels were always greater than standard practise levels (100% recommended fertiliser N and no compost, represented by the red dashed line).
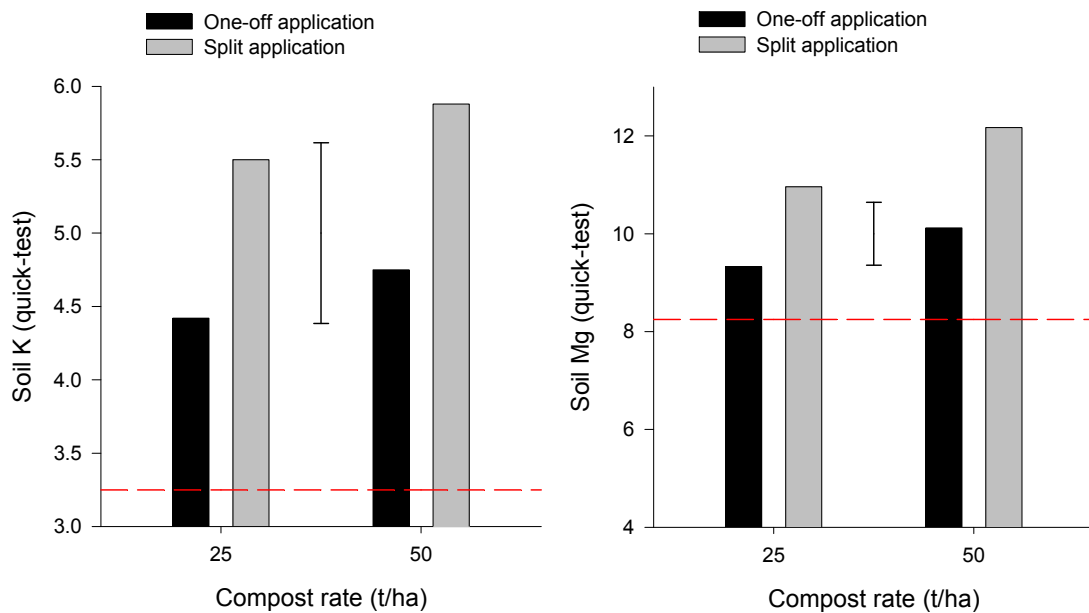

Figure 38: Effects of applying 25 and 50 t/ha as one-off or split applications on soil quicktest K and soil quicktest Mg at the arable crop trial (averaged for 2009-2012). Red dashed line represents standard practice. Bars represent 5% LSD with 22 df.

There is also some evidence that POM-C and N (as a percentage of total soil C and N) were greater where the compost had been applied as split applications, and this may explain the

greater overall yields obtained under those treatments. This was particularly apparent at the end of the third crop after the third and final split application where the percentage of C and N as POM was significantly greater where the compost rates had been split (P = 0.048 and P = 0.027, respectively). These results suggest that applying smaller rates at more regular intervals may better meet crop demands. As can be seen in Figure 39, regardless of whether compost is applied as one-off or split applications, percentage of C and N as POM was always greater than standard practise levels (100% recommended fertiliser N and no compost, represented by the red dashed line).
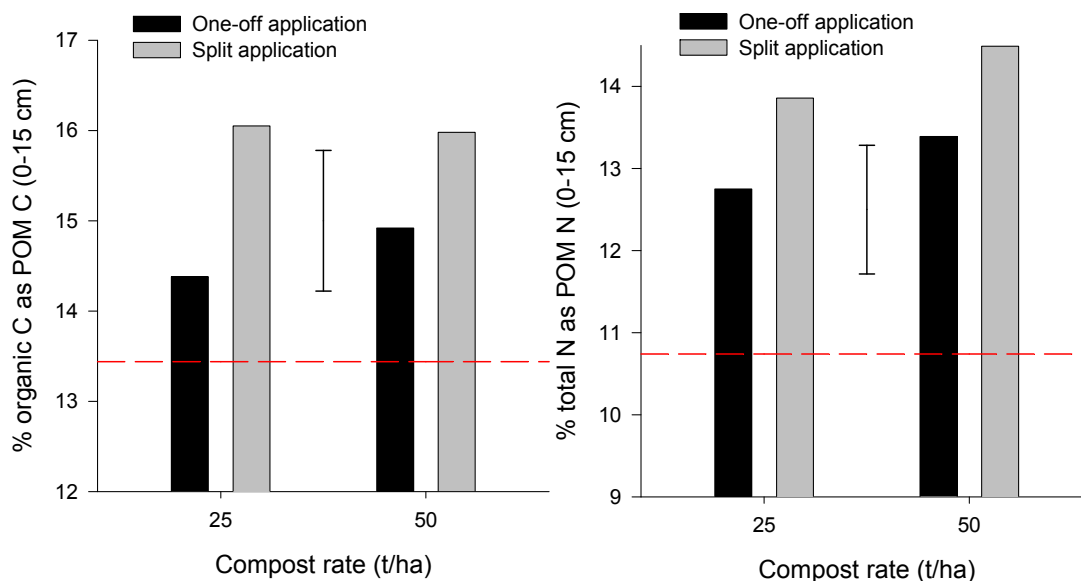

Figure 39: Effect of applying 25 and 50 t/ha as one-off or split applications on % of POM C from the total soil organic C pool and POM N from the soil total N pool in the top 15 cm at the arable crop trial (average for 2009-2012). Red dashed line represents standard practice. Bars represent 5% LSD with 22 df.

3.1.12   Fertiliser offsets from one-off and split applications of compost

In Figure 40 the red dashed line represents standard practise of 100% recommended fertiliser N and no additions of compost. Cumulative yield results again confirm that over the duration of a crop rotation 50 t/ha of compost may increase yields in the absence of fertiliser compared with the control, but overall compost without fertiliser leads to substantially lower yield then standard practise. These results strongly suggest that complete substitution of fertiliser with compost is not recommended. To get the best out of the compost it needs to be applied with the addition of fertiliser N. An interesting observation to be made from Figure 40 is that in the absence of compost cumulative yields did not increase between the 67 and 100% recommended fertiliser N rates but there were cumulative yield increases between these two fertiliser N rates in the presence of compost. These results suggest that without compost yields did not respond to additional available N and support results from the first crop (maize) where it was found that the response to available N increased significantly where compost was applied. The mechanisms that underpin this result are not fully understood and require further research.

These results also strongly suggest that one third of fertiliser N can be offset for at least 2 years following a one-off application of either 25 or 50 t/ha compost without compromising yields (this trend was most apparent for the 50 t/ha rate). Bearing in mind that split compost applications were only tested for the 33% and 67% recommended N rates, when compost was applied in split applications alongside two-thirds recommended fertiliser N rate, cumulative yields were

significantly higher than standard practise. Cumulative yield results also suggest that fertiliser N rates can be reduced even further when the 25 t/ha and 50 t/ha compost rates were applied in split applications over the 3 years. Reductions of fertiliser N to one-third recommended rates for 3 years with split 50 t/ha compost led to yields greater than standard practise and split 25 t/ha led to yields only marginally lower than standard practise.
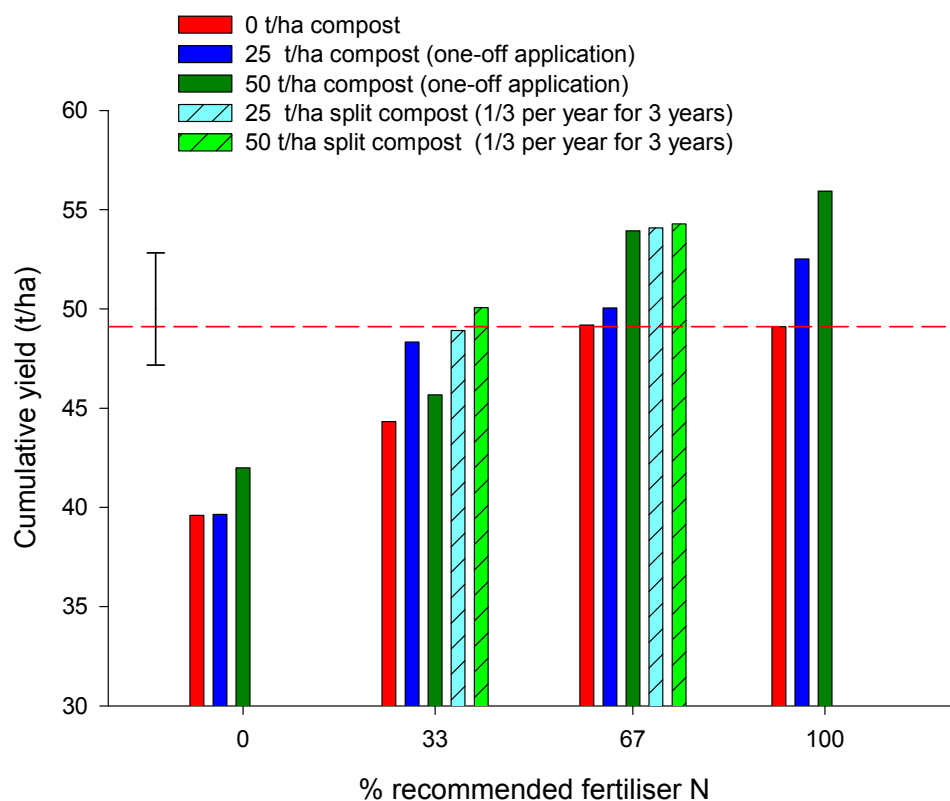

Figure 40: Effects of compost (one-off and split applications) and nitrogen treatments on the cumulative yield of all four crops grown at the arable crop trial. Red dashed line represents standard practice. Bar represents 5% LSD with 27 df.

In terms of profitability (Section 3.6) results from the arable crop trial show that reducing fertiliser to 33% of the standard rate of recommended N fertiliser was not profitable for any rate of compost. Reducing it to 66% of the standard rate of recommended N was, however, profitable, especially when split rates of compost were being applied annually.

When comparing whether 25 t/ha and 50 t/ha rates of compost should be applied as a one-off application or three split applications (restricted to just 33 and 67% recommended N) it appears that the split option is favourable. This was apparent for both yield results as well as soil measurements results such as POM.

3.4   Ex-forestry Trial, Bankside

The demonstration site located at Bankside was a simple presence/absence trial with three replicates of two treatments (50 t/ha compost v. no compost) designed to demonstrate the effect of compost application on a structurally compromised and low fertility soil (typical attributes of ex-plantation forest soils). Detailed results for the ex-forestry trial at Bankside have been presented in previous reports (Horrocks et al. 2010, Horrocks et al. 2011). Data from soil variates measured at the ex-forestry trial from baseline to harvest of the second kale crop are presented in Table 18.

Table 18: Treatment means with 5% LSD for each soil variate measured at baseline (pre-treatment, 2009) and at the end of both the 2009–10 and 2010–11 kale crops at the ex-forestry trial in response to compost rate.

	Compost rate (t/ha)	Baseline (2009)	End of 2009–10 kale	End of 2010–11 kale	Approx. average 5% LSD
Aggregate stability (mm, MWD)	0	2.1	1.0	2.0	0.3
	50	2.0	1.1	1.9	
Aggregate stability (%)	0	79.6	38.7	74.3	5.9
	50	75.4	43.3	73.3	
Total N (%)	0	0.36	0.40	0.37	0.13
	50	0.34	0.44	0.39	
Organic C (%)	0	6.3	6.3	6.7	2.5
	50	5.7	6.7	6.7	
C:N ratio	0	17.3	15.1	17.5	0.7
	50	16.9	15.4	17.0	
PMN (µg N/g)	0	38.7	71.9	65.4	41.5
	50	50.4	84.7	89.1	
pH	0	4.8	5.1	5.0	0.3
	50	4.8	5.1	5.3	
Olsen P (mg/L)	0	9.5	31.5	27.0	20.9
	50	11.3	19.7	39.3	
Potassium (QT)	0	3.7	12.7	5.7	7.3
	50	5.7	15.3	12.3	
Calcium (QT)	0	4.0	7.0	7.0	3.8
	50	3.7	7.7	10.0	
Magnesium (QT)	0	21.5	30.0	22.5	11.6
	50	22.0	33.7	32.7	
Sodium (QT)	0	4.0	7.0	5.0	2.4
	50	5.3	7.0	5.7	

QT = MAF quicktest units

As this site was recently out of forestry, areas of decomposing wood and pine cones were buried and scattered unevenly across the paddock. There was also very high, inconsistent stone content across the site. Both of these factors led to spatial variation that could not be accounted for with such low replication adopted for a demonstration site, despite the increase of plant sampling reps from 3 to 10 quadrats. The slightly undulating topography of the paddock also influenced the kale crop as it was not irrigated and the depression areas had noticeably more growth due to greater moisture availability during the dry 2010 autumn.

Even though significant treatment differences are more difficult to statistically detect with such low replication and so few observation points, mean differences can still be noted. The most notable differences between the compost-treated plots and control plots are in the dry matter yields, where the plots which received compost produced 1.55 t/ha or 48% more dry matter than the control plots after the first kale crop harvested in 2010. While the yield from all plots was slightly higher in the second crop, the effect of very high stone and wood content of the soil, the site being non-irrigated with low fertility, and poor soil physical condition again resulted in a very low overall yield compared with typical kale crops grown across Canterbury. Yields from the second 2011 harvested kale crop were higher where compost had been applied but the differences were no longer significant (Figure 41).
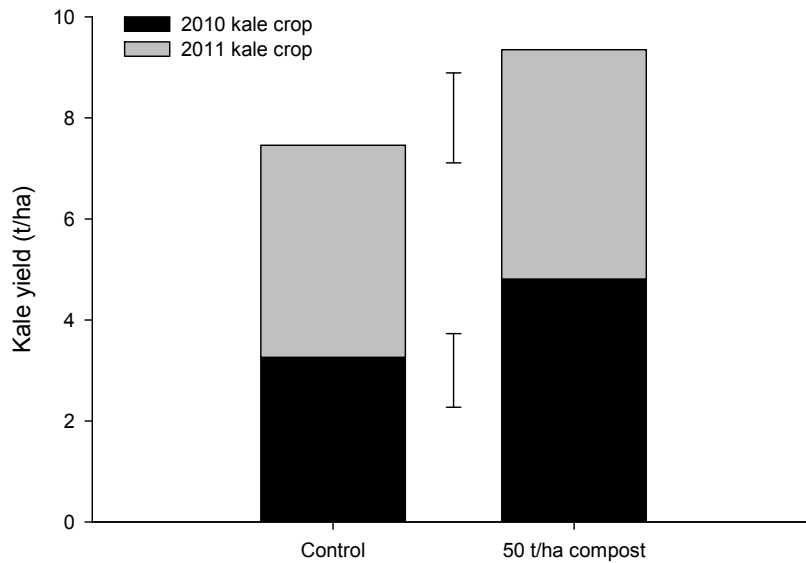
Figure 41: Effects of compost treatment on the dry matter yield of two consecutive kale crops (2010 and 2011) at the ex-forestry trial. Lower bar represents 5% LSD with 1 df for the 2010 crop and upper bar represents 5% LSD with 4 df for the 2011 crop.

There were some differences in soil measurements, most notably soil quicktest K and potentially mineralisable N, which both increased with compost ($P < 0.001$ and $P = 0.064$, respectively). Due to extremely high variability as a consequence of inconsistent stone and forest debris distribution overall soil parameter differences were not strong.

3.5   Intensive Vegetable Production Trial, Christchurch

Results from the first lettuce crop from the intensive vegetable production trial have been presented in the previous report, Horrocks et al. 2011. Detailed soil data and crop results from the subsequent cabbage and lettuce crops are presented in Tables 19–22.

Table 19: Mean soil results from the intensive vegetable production trial at baseline (pre-treatment, December 2010) and the end of the trial (March 2012) in response to compost and chicken manure treatment.

Soil measurement	Baseline	Control	Chicken manure @ 10 t/ha	Compost @ 14 t/ha	Compost @ 28 t/ha	5% lsd, 16 df
Mineral N (kg/ha)	12.3	260.3	227.0	237	257.0	67.70
AMN (kg/ha)	70.4	51.4	46.7	54.1	50.6	18.20
Total N (%)	0.33	0.37	0.32	0.34	0.33	0.14
Organic C (%)	4.40	4.72	4.13	4.31	4.13	2.15
C:N ratio	13.1	13.3	12.9	13.2	13.0	1.5
Total N (kg/ha)	513.0	579.9	503.5	537.8	510.3	219.1
Organic C (t/ha)	6.80	7.36	6.45	6.72	6.44	3.35
pH	6.2	5.6	5.6	5.6	5.6	0.08
Olsen P (mg/L)	111	142	141	136	140	11.80
CEC (me/100g)	23.5	24	22	22	21	6.23
Potassium (QT)	11.5	13	14	13	15	4.90
Calcium (QT)	17.5	18	17	17	17	2.24
Magnesium (QT)	30	35	33	34	35	2.67
Sodium (QT)	6.3	8.0	9.0	8.0	8.0	1.41
Boron (kg/kg)	1.9	1.8	1.7	1.7	1.7	0.36
Iron (mg/kg)	1177	1192	1167	1186	1086	45.95
Manganese (mg/kg)	19	20	22	20	22	4.00
Zinc (mg/kg)	8.9	8.8	8.7	9.4	9.5	2.90
Copper (mg/kg)	4.5	4.2	4.2	3.9	3.9	0.60
Cobalt (mg/kg)	0.7	0.6	0.7	0.7	0.6	0.05
Molybdenum (mg/kg)	0.9	0.9	0.9	0.9	0.9	0.32

QT = MAF quicktest units

Table 20: Treatment means with 5% LSD for each plant variate measured from the cabbage crop (second crop in the rotation following application of the treatments) at the intensive vegetable production trial in response to compost and chicken manure treatment.

| Variate	Control	Chicken manure @ 10 t/ha	Compost @ 14 t/ha	Compost @ 28 t/ha	5% lsd, 12 df	F-pr
Cabbage water content (%)	89.5	89.3	89.4	89.4	0.69	0.948
% marketable plants	85.0	89.0	83.0	77.5	14.21	0.397
Fresh yield of marketable plants (t/ha)	85.8	87.9	83.7	82.6	8.84	0.587
Fresh yield of marketable hearts (t/ha)	45.3	45.7	44.2	43.8	5.87	0.879
Mean weight of marketable plants (g)	2941	2976	2786	2839	213.3	0.237
Mean weight of marketable hearts (g)	1559	1563	1474	1528	143.9	0.529
Heart:whole plant ratio of all plants (%)	53.7	53.0	54.2	53.7	2.26	0.718
Heart:whole plant ratio of marketable plants (%)	53.9	53.7	54.3	54.9	1.60	0.429
Dry matter yield of all plants (t/ha)	8.86	9.31	8.85	8.68	0.610	0.186
Dry matter yield of marketable hearts (t/ha)	4.70	4.86	4.70	4.62	0.46	0.713
N uptake, all plants (kg/ha)	284	294	275	264	37.13	0.38
C uptake, all plants (t/ha)	3.45	3.63	3.51	3.41	0.220	0.203
C:N ratio	12.2	12.3	12.6	12.7	1.26	0.834
N uptake, marketable plants (kg/ha)	150	153	146	141	22.51	0.659
C uptake, marketable plants (t/ha)	1.83	1.89	1.86	1.82	0.16	0.710

Table 21: Treatment means with 5% LSD for each plant variate measured from the second lettuce crop (third crop in the rotation following application of the treatments) at the intensive vegetable production trial in response to compost and chicken manure treatment.

Variate	Control	Chicken manure @ 10 t/ha	Compost @ 14 t/ha	Compost @ 28 t/ha	5% lsd, 12 df	F-pr
Lettuce water content (%)	94.3	94.4	94.5	94.2	0.50	0.498
% marketable plants	92.2	92.5	88.6	88.5	7.56	0.514
Fresh yield of marketable plants (t/ha)	81.5	76.7	74.8	78.3	18.92	0.886
Fresh yield of marketable hearts (t/ha)	43.4	40.6	39.7	41.6	10.15	0.876
Mean weight of marketable plants (g)	1294	1250	1327	1305	128.4	0.628
Mean weight of marketable hearts (g)	690	668	704	695	78.4	0.781
Heart:whole plant ratio of all plants (%)	52.7	53.0	52.6	52.6	4.02	0.997
Heart:whole plant ratio of marketable plants (%)	53.1	53.4	53.0	53.1	3.94	0.997
Dry matter yield of all plants (t/ha)	4.70	4.29	4.05	4.46	1.012	0.563
Dry matter yield of marketable hearts (t/ha)	2.51	2.28	2.14	2.36	0.525	0.516
N uptake, all plants (kg/ha)	173	158	150	170	41.1	0.605
C uptake, all plants (t/ha)	1.83	1.66	1.57	1.73	0.387	0.548
C:N ratio	10.5	10.5	10.6	10.1	0.81	0.595
N uptake, marketable plants (kg/ha)	92.0	83.6	79.1	89.5	20.57	0.535
C uptake, marketable plants (t/ha)	0.97	0.88	0.83	0.92	0.203	0.511

Table 22: Treatment means with 5% LSD for cumulative yield and nitrogen variates measured from across all three consecutive crops at the intensive vegetable production trial in response to compost and chicken manure treatment.

Variate	Control	Chicken manure @ 10 t/ha	Compost @ 14 t/ha	Compost @ 28 t/ha	5% lsd, 12 df	F-pr
Fresh yield of marketable plants (t/ha)	242	248	232	235	35.4	0.771
Fresh yield of marketable hearts (t/ha)	123	126	119	118	21.1	0.861
Dry matter yield of all plants (t/ha)	17.6	17.8	17.1	17.4	1.29	0.651
Dry matter yield of marketable hearts (t/ha)	9.0	9.1	8.8	8.8	0.88	0.861
Total N taken up by plants (kg/ha)	618	629	593	595	57.4	0.464
Total N removed from paddock (kg/ha)	314	319	305	300	39.81	0.735

With this trial being fully replicated the large LSDs highlight that there were no significant differences in any measured plant parameter. Figure 42 shows cumulative fresh yield of marketable hearts and cumulative total N uptake. Although the yield and N uptake from the chicken manure treatment were slightly higher than both the 14 and 28 t/ha compost treatments, these differences were not significant with *P* values of 0.861 and 0.464, respectively. The lack of a strong difference between treatments and control is likely due to the high fertiliser inputs typical of intensive vegetable production which meant the full benefits of using amendments such as chicken manure or municipal compost was not allowed for. Olsen P values were also high. The Hill Laboratories online lettuce crop guide (www.hill-laboratories.com/file/fileid/21705) recommends that soil Olsen P levels be in the range of 35–90, whereas Olsen P values from the site far exceeded this (Table 19). These results do not suggest that there is no benefit from adding amendments such as chicken manure or compost in intensive vegetable production as the long-term use may improve physical parameters of the soil. Rather they suggest further work needs to address amendment management to ensure benefits of its use are maximised. This would involve quantifying fertiliser use reductions to offset nutrients available in the amendments in a way that does not compromise yields.
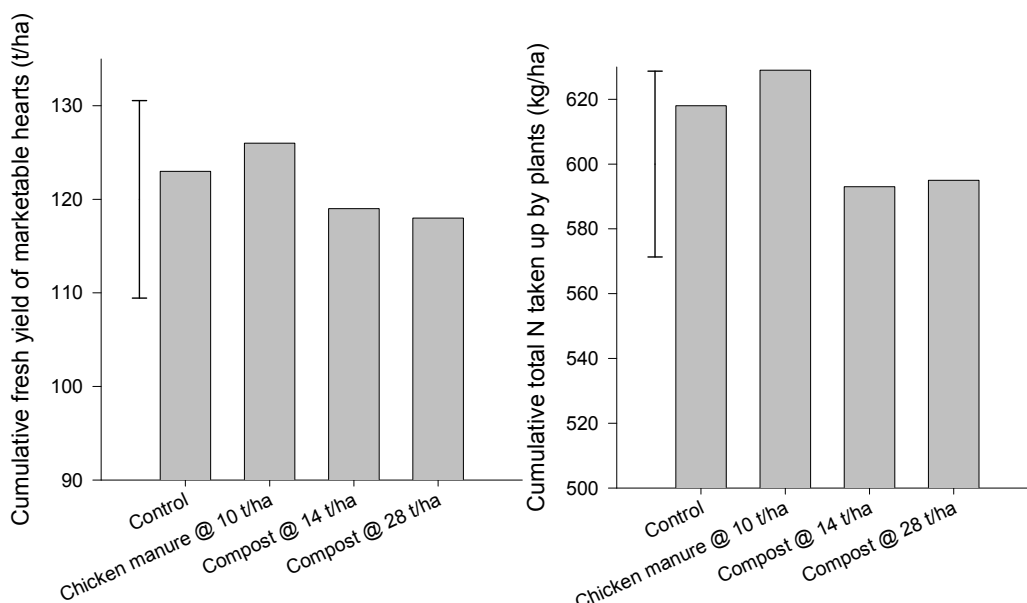
Figure 42: Effect of compost and chicken manure treatments on cumulative fresh yield of marketable hearts and total N uptake at the intensive vegetable production trial. Bars represent 5% LSD with 12 df.

3.6   Cost-benefit analyses

The cost-benefit analyses were based on standard costs of production for each crop. The calculations assumed a fixed cost for the purchase ($12.50/t) and spreading ($6.50/ha) of compost. The break-even freight rate ($/t) is the cut-off point above which higher freight costs would not be profitable. Scenarios are considered profitable if returns are greater or the same as standard practice (no compost and 100% of recommended fertiliser N recommended as though no compost was to be applied). The cost-benefit analysis does not take into consideration the financial value associated with soil structural and water holding capacity improvements that may result from adding organic matter to the soil. It assumes that benefits from adding compost in these trials had been exhausted, but some of the soil results suggest that this was not the case.

3.6.1 Forage Crop Trial

When comparing one-off applications of 25 or 50 t/ha of compost for two consecutive crops of kale it was found that applying 50 t/ha was more profitable than applying 25 t/ha (Table 23). When looking at profitability over a 1-year time scale in a rape crop with 12.5 t/ha of compost alongside a 40% reduction in fertiliser N it was found that this scenario was profitable (compared with standard practise) for freight costs up to $14.60 (Table 23).

Table 23: Break-even freight rates for the brassica crops with different compost rates and rotations.

Application rate (t/ha)	Time frame	N fertiliser (% of rec. rate)	Increase in yield above standard practice (%)	Break-even freight rate ($/t)
12 (one-off)	1-year rotation	60	13	$14.60
50 (one-off)	2-year rotation	100	31	$8.30
25 (one-off)	2-year rotation	100	12	$3.10
100 (one-off)	2-year rotation	100	45	$1.30
50 (one-off)	1-year rotation	100	48	Not measured

Figure 43 presents gross margins for a mostly forage crop rotation of four consecutive crops; it can be seen that when compared with applying no compost at all (the dashed red line) gross margins were highest when a one-off application of 50 t/ha of compost was applied as long as the freight costs were less than $17/t. Over the 3-year rotation applying 25 t/ha was not profitable compared with standard practise. Applying a 12.5 t/ha was profitable in the year of application as long as freight costs did not exceed $13/t.
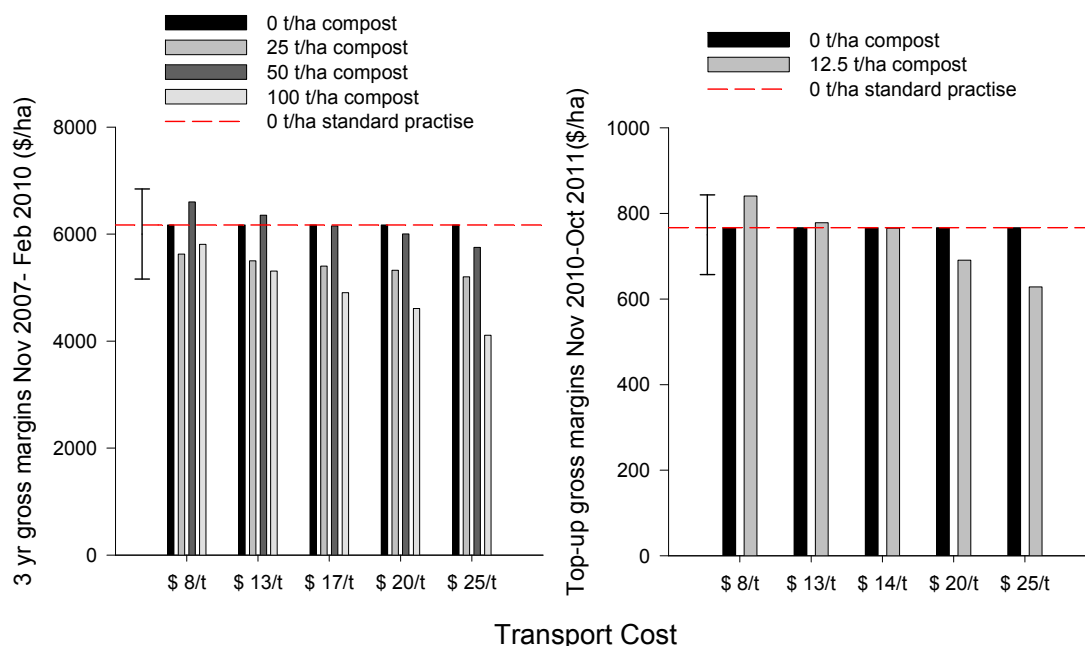
Figure 43: Gross margins for different rates of compost (0, 25, 50 100 t/ha) and for the 12.5 t/ha top-up at the forage crop trial for the first 3 cropping seasons. Red dashed line represents standard practice. Bars represent 5% LSD with 20 df.

3.6.2   Arable Crop Trial

The most profitable scenario at the arable crop trial was 25/t of compost applied in three split applications over 3 years (approx. 8 t/ha per application) combined with 66% of the standard rate of N fertiliser (Table 24). The second most profitable scenario was applying compost at a one-off rate of 50 t/ha. As was the case at the forage crop trial it was more profitable to apply a one-off of 50 t/ha than a 25 t/ha rate of compost.

Table 24: Break-even freight rates for one-off and split applications of compost following the 3-year arable crop trial.

Application rate (t/ha)	Time frame	N fertiliser (% of rec. rate)	Increase in yield above standard practice (%)	Break-even freight rate ($/t)
8 (yearly)	3-year rotation	66	10	$33.80
50 (one-off)	3-year rotation	100	14	$18.50
17 (yearly)	3-year rotation	66	11	$7.50
25 (one-off)	3-year rotation	100	7	$6.40
50 (one-off)	3-year rotation	66	10	$5.80
8 (yearly)	3-year rotation	33	0	-$1.90**
17 (yearly)	3-year rotation	33	0	-$6.90**
25 (one-off)	3-year rotation	66	2	-$17.90**

** Any yield benefits beyond the time frame reported would improve the profitability.

Figure 44 shows that unless the 25 t/ha compost rate was split across 3 years it was not profitable over the duration of the crop rotation trialled. Results from the arable crop trial show that reducing fertiliser to 33% of the standard rate of recommended N fertiliser was not profitable for any rate of compost. Reducing it to 66% of the standard rate of recommended N was, however, profitable, especially when compost was applied annually using split applications.
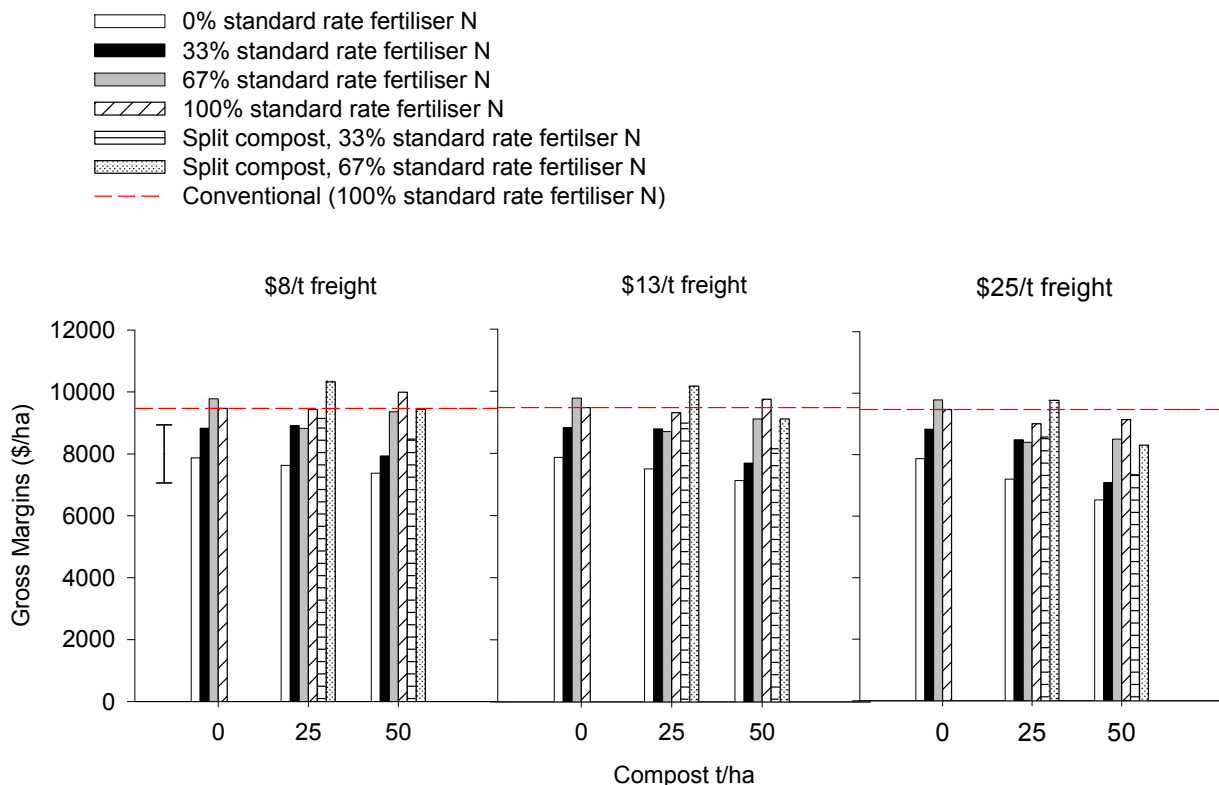

Figure 44: Gross margins at the arable crop trial for different rates of compost (0, 25, 50 t/ha), one-off and split applications of compost, and different freight cost scenarios. Bar represents 5% LSD with 30 df.

3.7   Incubation study

Many of the nutrients supplied from compost are made available through the mineralisation of the compost organic matter by soil microbes, resulting in the release of plant available nutrients. The release of plant available nutrients during the breakdown of compost organic matter depends to a certain extent on the amount of readily decomposable C in the compost used. There are a number of different environmental factors that also influence the rate of compost breakdown and the release of plant available nutrients, in particular temperature and moisture. To better understand the conditions that enhance mineralisation of nutrients from compost, an incubation study was conducted.

Figure 45 shows that the dynamics and amount of soil respiration were significantly affected by the incubation temperature and moisture content (rate of respiration increased as moisture content and temperature increased). The rate of respiration, regardless of moisture content, markedly increased over 18°C. There were no differences in respiration rates between the with and without compost treatments at day 75, suggesting that by this time most of the labile C supplied in the compost had been exhausted.

Though greater respiration with compost is indicative of microbial activity, it does not necessarily mean that other nutrients such as N are being released as this depends on the amount of labile organic matter and the quality of that organic matter (e.g. the C:N ratio). If C:N ratios are high then N may be immobilised to decompose the compost.
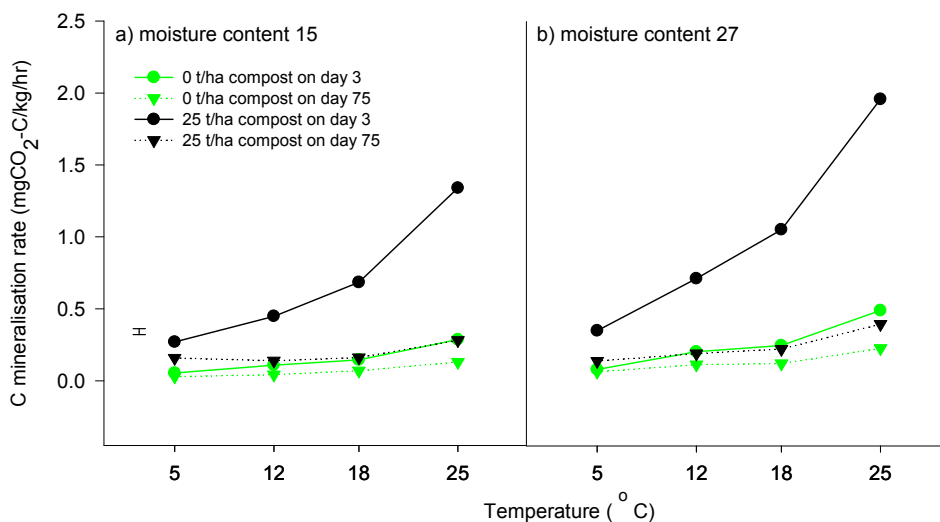

Figure 45: C mineralisation rate with and without compost at day 3 and day 75 incubated at 5, 12, 18 and 25°C and at moisture contents of 15 and 27% (g/g). Bar represents 5% LSD with 93 df.

Temperature, moisture and the presence of compost also increased the rate of N_2O emissions. At a moisture content of 15% there is a trend for a greater N_2O emission rate after 3 days with compost but this difference is only significant at a moisture content of 27% with temperatures greater than 18 degrees C (Figure 46). Small amounts of N_2O losses are to be expected in zones of higher moisture or pockets where oxygen is lacking, however, this combination of high soil temperatures and moisture content close to field capacity would occur relatively infrequently under field conditions. N_2O is a greenhouse gas and its loss is indicative of the reduction of nitrate and is a loss of plant available N from the system. Though the rate was significantly higher where compost was applied and at the highest temperature and moisture contents, the overall rate of N_2O loss was small compared with total N and is in keeping with the inevitable losses of around 1% of N as N_2O that is expected from organic matter (Novoa & Tejeda 2006).
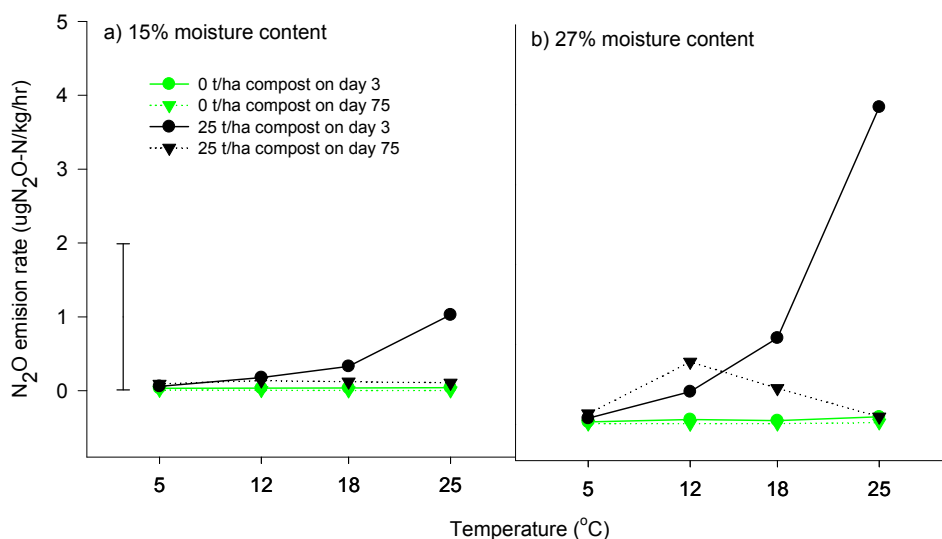
Figure 46: N₂0 emission rate with and without compost at day 3 and day 75 incubated at 5, 12, 18 and 25°C and at moisture contents of 15 and 27% (g/g). Bar represents 5% LSD with 93 df.

As expected, the cumulative amount of C mineralised (CO_2 microbial respiration) increased with increasing moisture content and temperature (Figure 47). These results are apparent both with and without compost but are more apparent with compost, suggesting that more aerobic respiration is taking place where there is an organic matter energy source.

Compost used in the incubation had % C of 20.4, equivalent to 13.5 g C (from compost) per kilogram of soil. The difference between respiration of soil with compost and soil without compost (the green and black lines) is compost-induced respiration. On average, across the two different moistures and four different temperatures, the compost-induced respiration equates to 471 mg CO_2/kg soil (or 0.47 g CO_2/kg soil). This means roughly only 3.5% of total C has been utilised. This suggests that only a very small amount of the C that is present in the compost has been used as a source of microbial energy during this incubation period, suggesting that most of the C present is in more resistant, slowly decomposing pools.
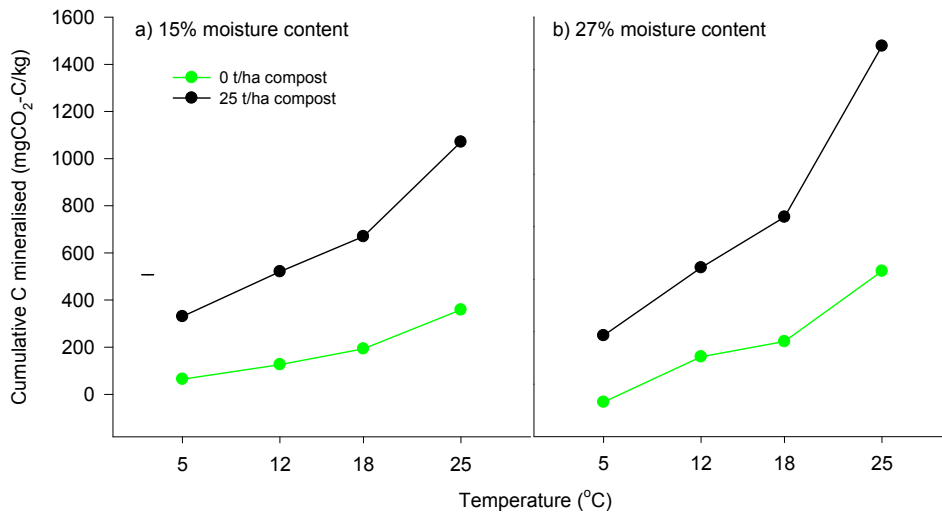
Figure 47: Cumulative C mineralised with and without compost incubated at 5, 12, 18 and 25°C and at moisture contents of 15 and 27% (g/g). Bar represents 5% LSD with 45 df.

In the absence of compost the expected pattern emerged with increasing temperature and moisture resulting in mineralisation (Figure 48). Where compost is present the initial mineral N amount is a lot higher. When background concentrations of mineral N are high it is expected that there will be greater variability, making it difficult to detect if fluctuations over time are due to net mineralisation or a consequence of high background N. There is, however, some evidence of net mineralisation occurring at 25°C and net immobilisation occuring at 12°C over the 89 days of the incubation study. This suggests that when compost is applied in field conditions there will be an immediately available N source (i.e. mineral N) that the crop will be able to access, but mineralisation of the organic N present in the compost is likely to be relatively small during the growth of the first crop. The more resilient pools of C and N still present will slowly decompose over time gradually releasing N to subsequent crops.
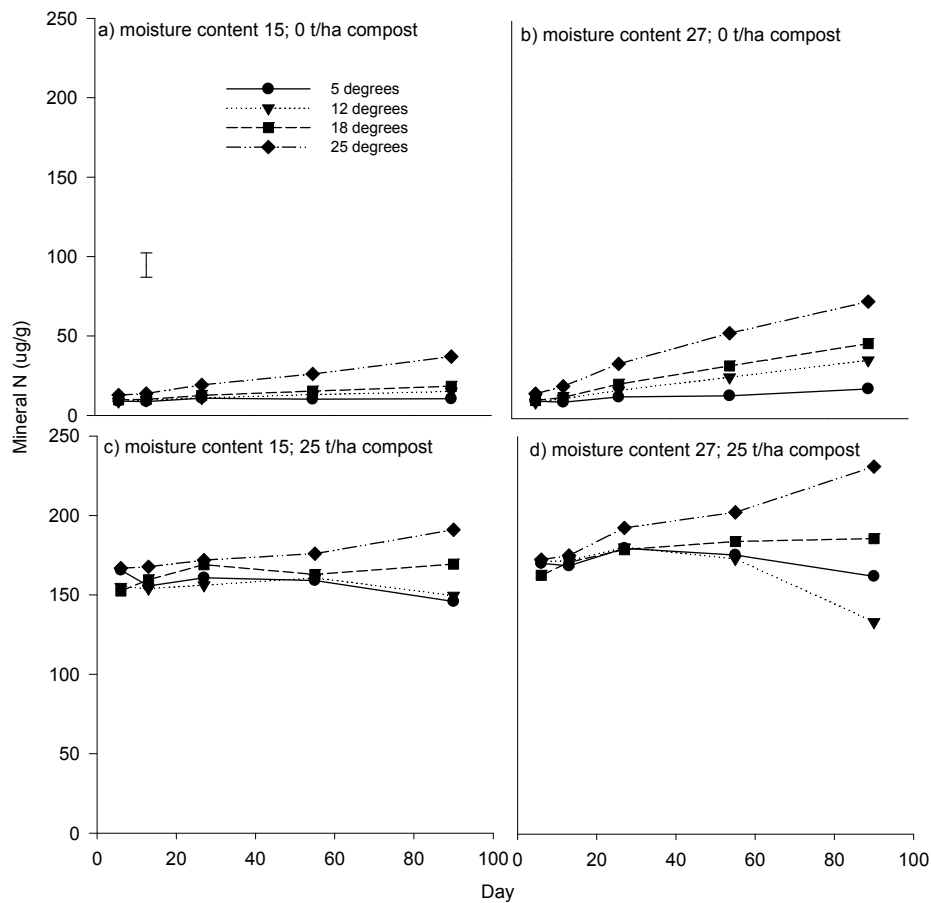
Figure 48: Net mineral N with and without compost at 5, 12, 18 and 25°C and at moisture contents of 15 and 27 % (g/g). Bar represents 5% LSD with 192 df.

Figure 49 illustrates that initially most of the mineral N from the compost was in the form of ammonium and that there was no ammonium in the without compost treatments. Depending on the temperature over 2-8 weeks this was converted to nitrate (Figure 50). A benefit of having the mineral N in the form of ammonium in the compost is that it will not leach in this form but it is able to be taken up by the crop. The cooler the soil temperature the longer the ammonium persists which may minimise leaching potential when compost is applied in autumn.
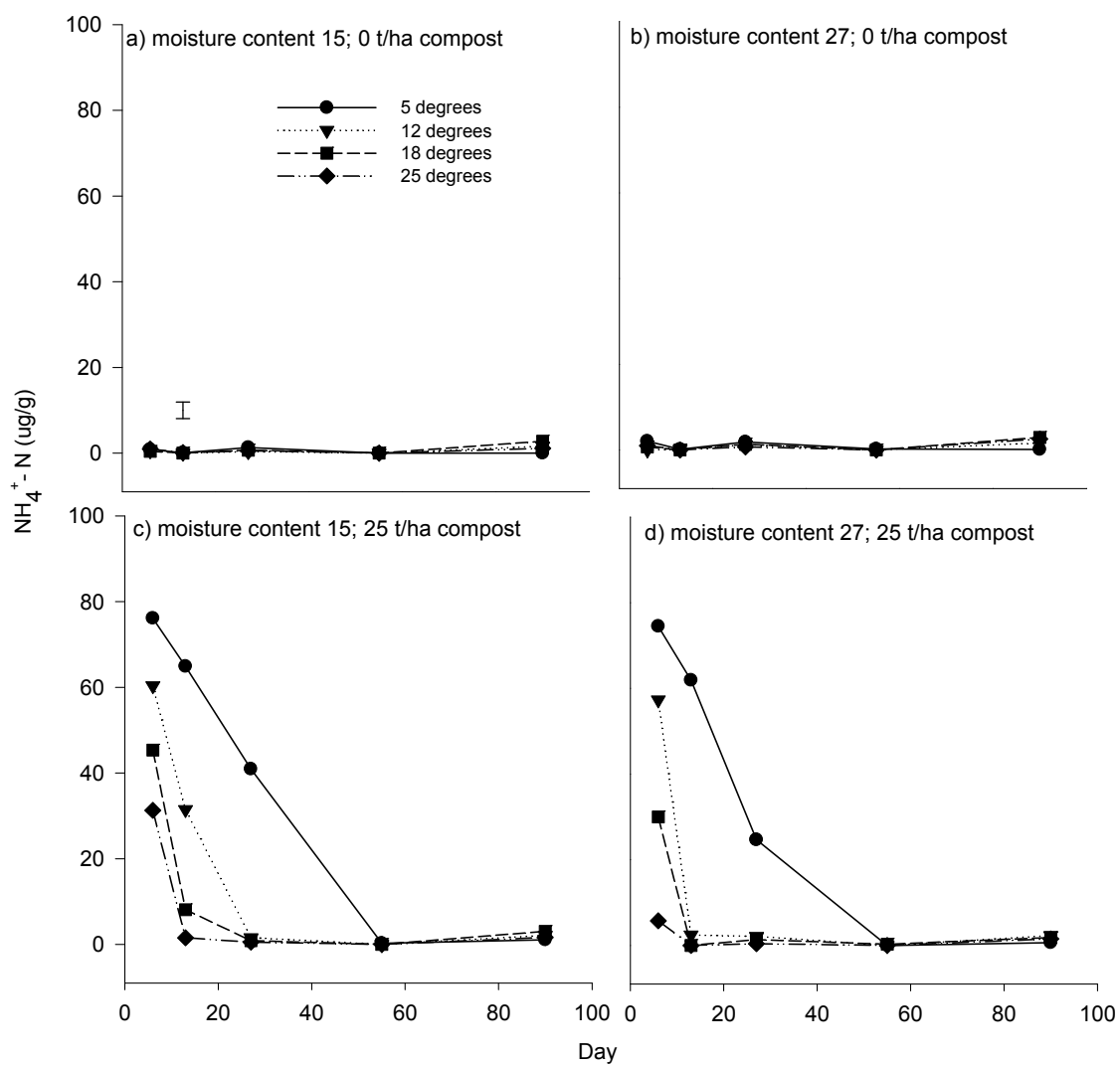
Figure 49: Net ammonium produced with and without compost at 5, 12, 18 and 25°C and at moisture contents of 15 and 27% (g/g). Bar represents 5% LSD with 192 df.
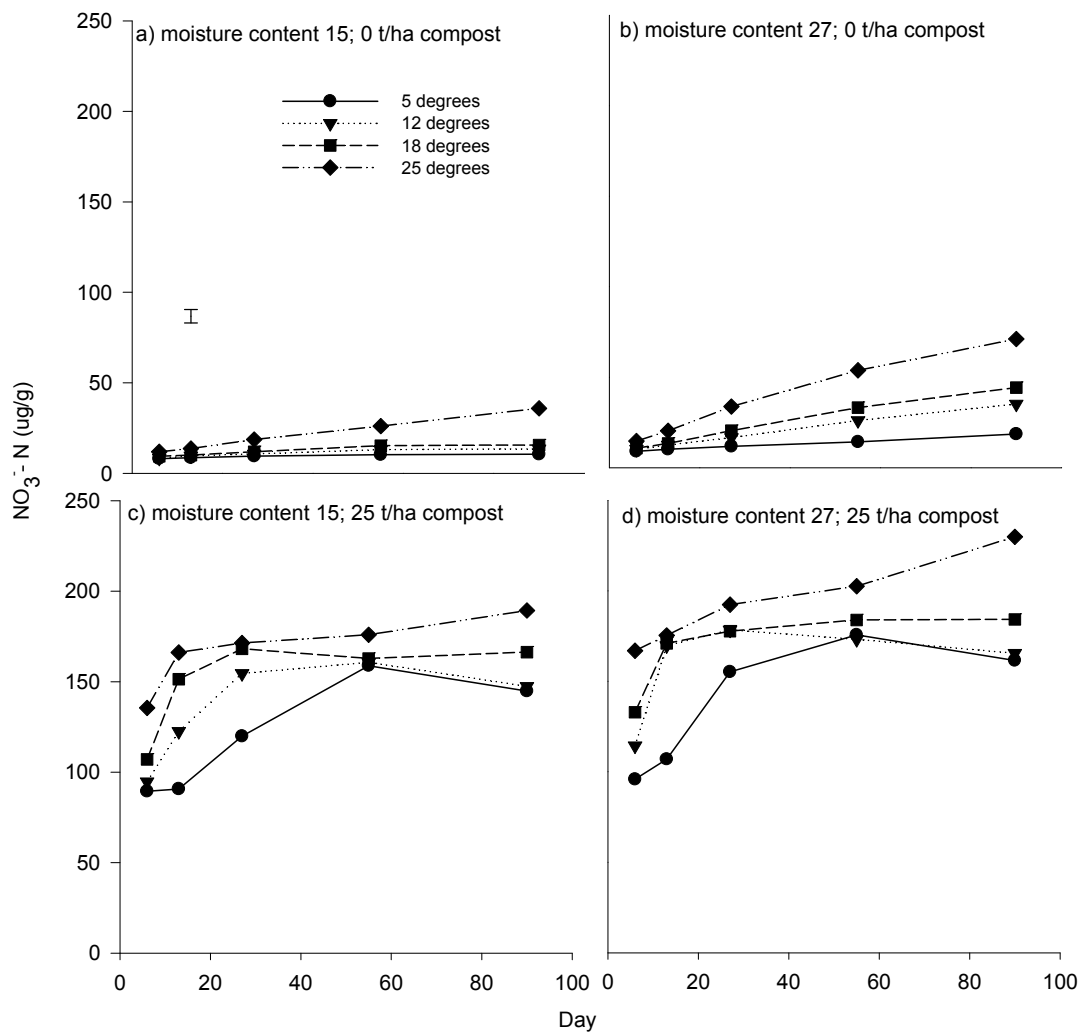
Figure 50: Net nitrate produced with and without compost at 5, 12, 18 and 25°C and at moisture contents of 15 and 27% (g/g). Bar represents 5% LSD with 192 df.

The compost-induced respiration results suggest that only a very small amount of the C that is present in the compost in the crop following its application is likely to be used as a source of microbial energy as most of the C present is in more resilient, slowly decomposable pools. The mineralisation results suggest that there will be an initial flush of nutrients that will be plant available, further nutrient release would be expected over time as these resilient pools start to decompose. This may help to explain why elevated nutrient availability is still measurable years after the compost has been applied.

4   Conclusions

Results indicate that mature municipal compost can enhance crop production for at least 2 years following a single application in arable, pastoral and forage cropping systems. Small regular applications of around 8–12 t/ha with fertiliser N offset by one third was found to be the most financially viable scenario, and results suggest that applications should be made regularly (i.e. every 1–2 years). Results also suggest that larger one-off applications of 25–50 t/ha may require reapplication of the same rate every 3–4 years and that over a 3-year cropping rotation 50 t/ha was more financially viable than 25 t/ha.

Using compost in intensive high input vegetable production systems did not result in yield responses due to high fertiliser inputs typical of intensive vegetable production. These results do not suggest that there is no need for adding amendments such as chicken manure or compost in intensive vegetable production. Rather, they suggest further work needs to address amendment management to ensure benefits of its use are maximised. This would involve quantifying fertiliser use reductions to offset nutrients available in the amendments in a way that does not compromise yields.

Although a crop's ability to respond to available N (from soil, fertiliser and compost reserves) increased where compost had been applied a complete substitution of fertiliser with compost is not recommended. To get the best out of compost it needs to be applied with fertiliser N. Results show that there is the potential to reduce N inputs without compromising yields. Other important crop nutrients besides N (such as P and K) are also being provided by the compost, with compost additions resulting in elevated soil levels of these nutrients for prolonged durations. Soils that have been cropped for a number of years or that are inherently low in nutrients such as P and K may especially benefit from using compost and fertiliser as additive components to meet crop nutrient requirements.

Results from the laboratory incubation study indicated that there was more microbial activity in the presence of compost and a high starting point for mineral N, suggestive of short-term crop benefits. The rate of net accumulation of N (mineralisation) over the 89 days of the incubation, however, did not differ from the without compost incubation as most of the C and N from the compost was in resilient pools that were slow to decompose, suggestive of a slow release of further nutrients over time.

Nitrate leaching trended towards increasing the higher the rate of fertiliser N applied but adding compost did not lead to greater leaching. This may be because available N in the compost was found to be in the non-leachable ammonium form. The trend for more nitrate leaching with increasing fertiliser N suggests there may be potential to reduce total N leached if compost applications result in offsets to fertiliser applications.

Soil organic matter and carbon content increased significantly where compost was applied. Although there were trends towards improved soil structural stability and water holding capacity these were only apparent with high rates of compost. It is possible that soil structural improvements with time may require sustained applications of compost.

Particulate organic matter (significant to SOM turnover because it serves as a readily decomposable substrate for soil micro-organisms and as a short-term reservoir for plant nutrients) and available N levels were still elevated where compost had been applied at both the arable and forage rotation trials. These results suggest that it is plausible that subsequent crops may still benefit from compost beyond the scope of these trials.

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