Enhancing forage crop production and soil quality with municipal compost

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Abstract

The effects on forage crop yield and quality and associated soil quality properties of applications of municipal compost were examined in a multi-year, on-farm forage rotation trial established in 2007. Following the application of 0, 25, 50 or 100 t ha^{-1} of high quality municipal compost to a dryland site, two consecutive crops of forage kale were established. Kale yields were up to 50% greater following the addition of 100 t ha^{-1} compost than when no compost was applied. Results show that improvements in yield can continue for at least 2 years following a single application of compost. The ability of the soil to hold more water increased with rate of compost applied, as did organic C and anaerobically mineralisable N and soil pH. This study is the first time mature municipal greenwaste compost has been field trialled in New Zealand. Its results indicate that compost, applied in sufficient amounts, can enhance forage crop production and improve soil quality. Measurements over the next 3 years will enable the longer-term benefits of compost in forage rotations to be quantified and guidelines for the sustainable use of compost to be developed for New Zealand's agricultural systems.

Additional keywords: kale, Canterbury, mineralisable nitrogen, soil organic matter, forage quality

Introduction

Waste management regulators in many New Zealand cities are turning to compost production to reduce volumes of municipal garden and kitchen wastes currently disposed of in landfills around the country. Given the large amounts produced, composting industries are increasingly looking to the agricultural sector as a potential high volume end user of compost products. International research has shown that the organic matter content and N status of high quality municipal compost are beneficial as a soil conditioner and a slow release fertiliser (Sullivan *et al*., 2002; 2003). However, there is currently very little New Zealand-based research and no established guidelines to support the sustainable use of compost in New Zealand agricultural systems.

This paper describes the effects of a one-off application of municipal compost at different quantities to the yield and quality of two consecutive forage kale crops and to associated changes in soil quality. Quantifying the effects of applying compost to forage crops is the first step to providing farmers with information that will enable them to use compost efficiently and with confidence.

Materials and Methods

Experimental details

An on-farm forage rotation trial was established in 2007 to measure changes in forage crop yield and quality, and associated soil quality properties, following the application of different quantities of municipal compost. The trial is being conducted on a dryland sheep/beef grazing property at Albury, New Zealand (44° 16' 12" S, 170° 54' 0'' E), where long-term average rainfall is 650 mm per year. The soil is an alluvial Templeton silt loam (Typic Immature Pallic) of approx. 0.5-1 m depth overlying greywackegravels (Kear *et al*., 1967). Soil nutrient concentrations were measured to a depth of 150 mm prior to trial establishment and were: mineralisable N 91.3 kg N ha^{-1}; Olsen P 38.2 mg l^{-1}, exchangeable K 0.42 meq 100 g^{-1}; exchangeable Ca 12.6 meq 100 g^{-1}; exchangeable Mg 1.45 meq 100 g^{-1}; exchangeable Na 0.09 meq 100 g^{-1}; and pH 6.2. The water content at field capacity in the top 75 mm of soil was 31.6% of dry weight. The soil organic C in the 0-75 and 75-150 mm depths was 30.1 and 25.0 t C ha^{-1}, respectively. The soil fine earth bulk density in the 0-75 and 75-150 mm depths was 1.26 and 1.31 g cm^{-3}, respectively. The compost used in this study was made to commercial standards (NZS 4454:2005, Composts, Soil Conditioners and Mulches) prescribed by Standards NZ using municipal greenwaste and food waste (no biosolids) from Timaru, New Zealand, and supplied by Transpacific Waste Management. The compost used in this study had 8 weeks active composting, followed by 9 months of maturation, and was composed of 2.2% total N, 21.0% organic C, 0.46% P, and 1.27% K, on a dry weight basis and had a pH of 7.7.

Experimental design

The trial was established with 28 plots of 40 m x 20 m in an extended Latin Square design with seven replicates for each of 4 treatments (Figure 1). The extended Latin Square design was used to account for any spatial variability in topsoil depth, stone content and grazing orientation. Compost was applied at 0, 25, 50 or 100 t ha^{-1} (fresh weight; equivalent to 18, 35 or 70 t ha^{-1} dry weight). The compost was surface broadcast in a one-off application to a fallow paddock on 7 November 2007. The compost was not soil-incorporated. The first crop of kale (`Sovereign') was direct drilled on 8 November 2007 at a seed rate of 4 kg ha^{-1}.

No fertiliser was applied at sowing. All plots received 100 kg ha^{-1} of urea (46% N) and 7 kg ha^{-1} boron 15G (15% B) in mid-December 2007, and a further 25 kg ha^{-1} of urea in January 2008 (total N applied to first crop was 58 kg ha^{-1}). The kale was strip-grazed by a herd of 65 beef cattle between 1 June and 16 September 2008.

The trial was sub-soiled on 3 November 2008, and then direct drilled on 10 November 2008 to establish a second crop of kale (`Sovereign') at a seed rate of 4 kg ha^{-1}. At drilling, 150 kg ha^{-1} of a mineral mix fertiliser (10% N, 4% P, 1% K, 0.4% S) was applied followed by 80 kg ha^{-1} of urea on both 17 January and 11 February 2009 (total N applied to the second crop was 89 kg ha^{-1}). A small application of boron was also made on the latter date. The kale was strip grazed by up to 170 dairy heifers between 22 May and 19 June 2009.0

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

Figure 1: Layout for both the first and second forage rotation kale crops, with seven replicates of four compost rate treatments (0, 25, 50, 100 t ha^{-1}) in an extended Latin Square design.

Measurements

Crop measurements

The dry matter of the kale crops was measured in May 2008 and May 2009, just prior to initiating grazing of each crop. To achieve this, all above ground matter was removed from three representative 1 m^2 sample areas in each plot. After determining their wet weight, 5 typical plants were removed from each sample, dissected into stem and leaf and oven-dried at 60°C. Dried samples were ground (<1 mm) and analysed for feed quality (e.g. lipid, crude protein and ash content).

Soil measurements

Baseline soil measurements were made before compost was applied at the site. Pre- and post-grazing soil measurements were made in the 2008 kale crop and pre-grazing soil measurements were made in the 2009 kale crop. Samples were collected from 0-75 mm and 75-150 mm depths and analysed for a range of physical and chemical parameters. At each sampling, the bulk density was calculated from soil cores of a known volume, soil wet weight, and moisture content. Soil chemical analyses were completed on soils sieved <4 mm and air-dried at 25°C. Anaerobically mineralisable N (AMN) was determined by incubating the soil under waterlogged (i.e. anaerobic) conditions at 40°C for 7 days (Keeney, 1982), and measuring the KCl-extractable mineral N content of incubated soils, corrected for mineral N content of non-incubated soil. Mineral nitrogen in the extracts was measured using a Flow Injection Analyser. Total soil C and N were measured on air-dried ground (<2 mm) soils by Dumas combustion using a LECO TruSpec analyser (McGill and Figueirdo 1993).

Data analysis

The data were analysed 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 calculated, 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 Ltd, UK).

Results

The dry matter (DM) yield of the first (2007-08) kale crop increased with increased quantities of compost (P<0.001);

the DM yield of kale receiving 100 t ha^{-1} of compost was more than 50% greater than that of the control (Figure 2).

The effects of the original (one-off) compost application were still apparent in the second (2008-09) kale crop though to a lesser extent (P=0.086). While the DM yield of the second crop in the control plots (0 t ha^{-1} compost applied) was nearly 1.8 t ha^{-1} higher than that of the first crop, the DM yield of the crop receiving 100 t ha^{-1} of compost was an average of 33% greater than that of the control (Figure 2).

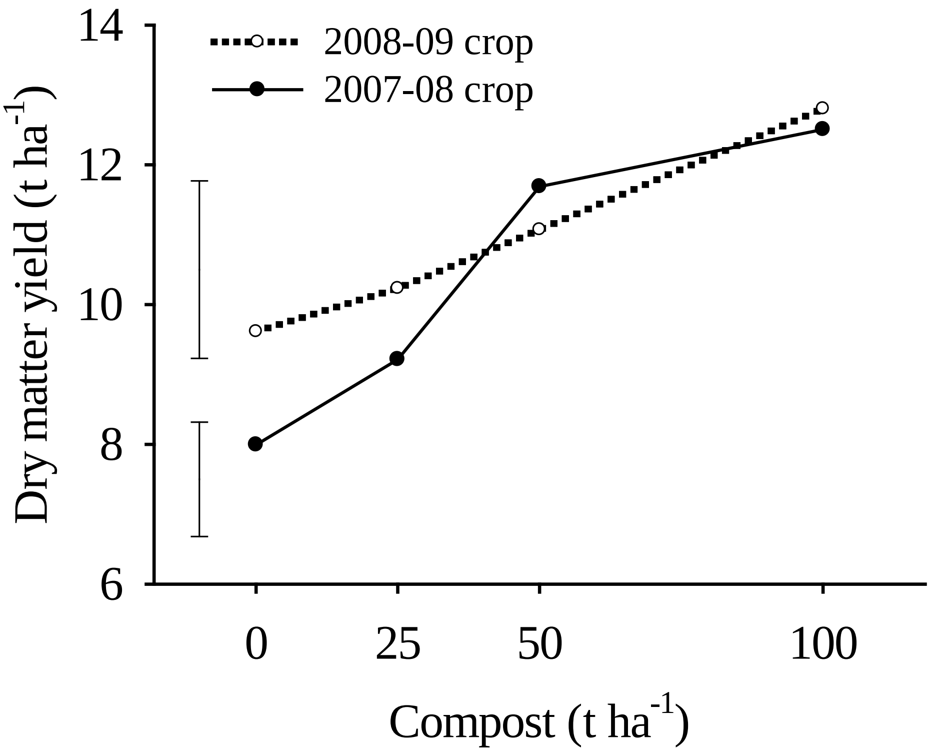

Figure 2: Effects of compost on dry matter yield of the 2007-08 and 2008-09 kale crops. Bar adjacent to control point represents LSD (5%, t = 2) for comparison within a crop year.

The forage quality properties (e.g. lipid content) of the first kale crop also increased with increasing rate of compost application (Table 1). The lipid, crude protein and ash content of the first kale crop that received 100 t ha^{-1} of compost was 22, 20 and 25% higher than in the control, respectively. However, in the second (2008-09) kale crop the lipid content actually decreased with compost rate while the other properties (crude protein and ash content) were unaffected by compost rate.

Table 1: Effects of the compost treatments on forage quality properties of the first (2007-08) and second (2008-09) kale crops.

	Rate of compost (t ha^{-1})				
	0	25	50	100	LSD (5%)
	Lipid (%, w/w)				
First crop	2.7	2.9	3.1	3.3	
Second crop	3.7	3.9	3.5	3.3	0.46
	Crude Protein (%, w/w)				
First crop	11.1	10.4	11.6	13.3	
Second crop	18.5	17.7	17.2	17.2	2.31
	Ash Content (%, w/w)				
First crop	6.7	6.3	7.2	8.4	
Second crop	8.7	8.7	8.7	8.5	1.05

Several soil properties measured immediately before winter grazing were affected by compost applications. The water content of soils at field capacity increased with the amount of compost applied (Figure 3). This effect was slightly higher in the second crop - soil receiving 100 t ha^{-1} of compost held over 8% more water than the control.

By the end of the first crop of kale there was a highly significant effect ($P<0.001$) of compost rate on soil organic C content in the top 75 mm of soil (Figure 4). While this effect was still present after the second crop ($P<0.001$), the overall values across the trial were lower. The effect of increasing compost rates on the soil organic C content in the 75-150 mm depth of soil was not as evident ($P=0.06$) as in the surface soil following the 2007-08 crop (Figure 5). By the end of the second crop (2008-09) the rate of compost applied did not have a significant effect on organic C content in the 75-150 mm soil layer.

In spring 2008, prior to sowing the second kale crop, up to 75 kg N ha^{-1} more anaerobically mineralisable nitrogen (AMN) was measured in the top 150 mm of soil in compost-treated plots than in the control (Figure 6). However, the effect of compost rate on AMN declined by the spring sampling in 2009 following the second kale crop; plots receiving 100 t ha^{-1} of compost had only an additional 33 kg ha^{-1} of AMN compared with the control. There was also a significant difference between years in the amount of AMN measured in the control treatments. In this case, the amount of AMN measured in the control treatments, following the first kale crop, was nearly 1.5 times that measured at the baseline and after the second kale crop.

Soil pH also increased from approx. 6.0 at baseline to 6.5-6.7 during the first year when compost was added ($P<0.001$; Figure 7).

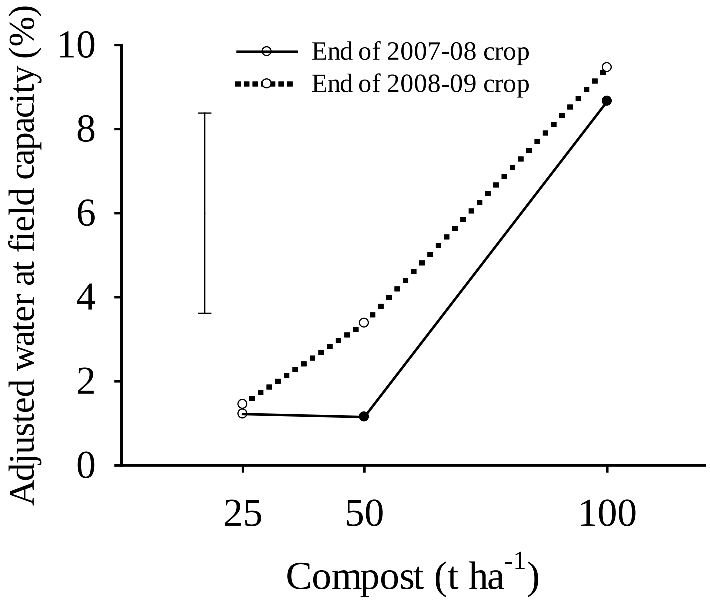

Figure 3: Effects of compost application, relative to the no compost treatment, on the soil water content at field capacity prior to each of the two kale crops being grazed. Bar represents 5% LSD, t = 2.

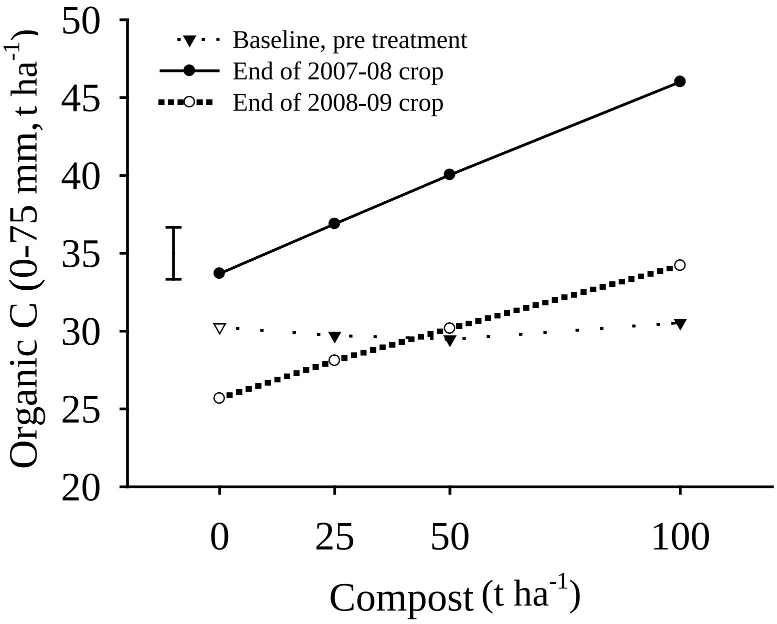

Figure 4: Effects of compost on the 0-75 mm soil organic carbon (C) concentration (t C ha^{-1}) of the forage rotation trial. Bar represents 5% LSD, t = 2.

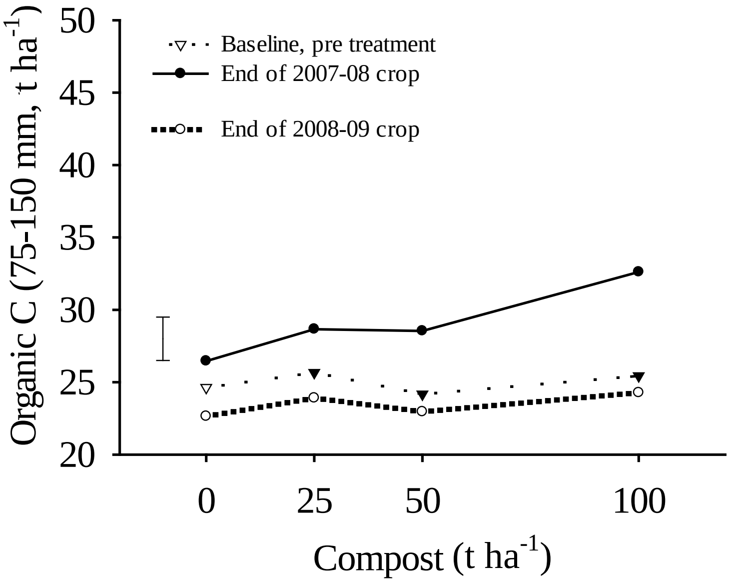

Figure 5: Effects of compost on the 75-150 mm soil organic carbon (C) concentration (t C ha^{-1}) of the forage rotation trial. Bar represents 5% LSD, t = 2.

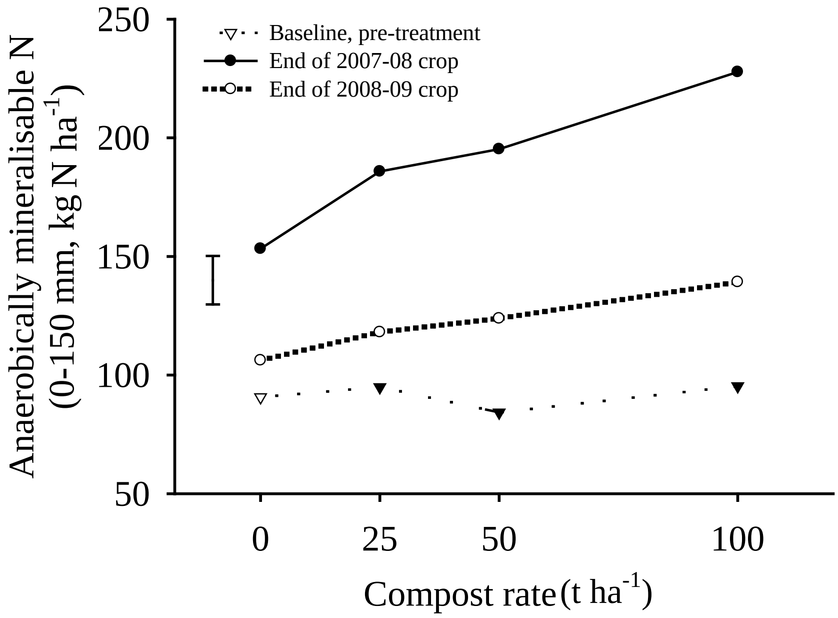

Figure 6: Effects of compost on anaerobically mineralisable N (kg N ha^{-1}) in the 0-150 mm soil depth prior to compost treatments being imposed and after each of the two kale crops had been grazed. Bar represents 5% LSD, t = 2.

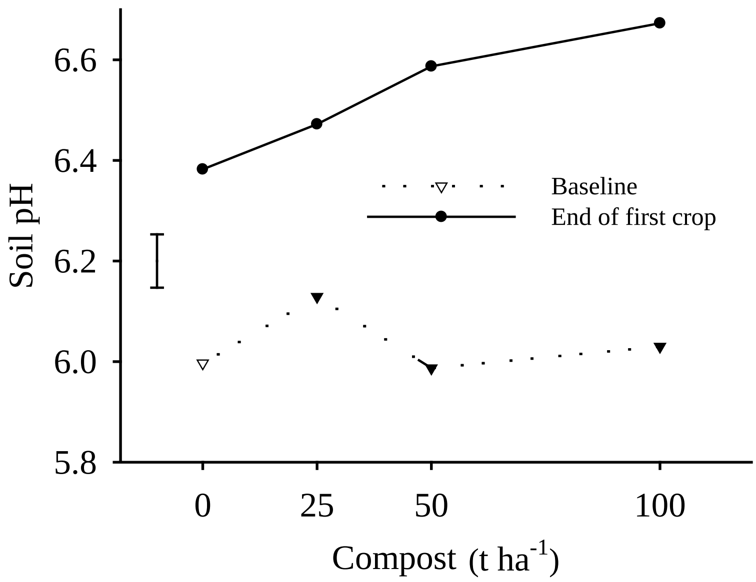

Figure 7: Effects of compost treatment on the soil pH from the forage rotation trial. Bar represents 5% LSD with 44 df.

Discussion

The results of this study showed that a single application of municipal compost significantly improved the DM production of forage kale over 2 consecutive years following application. The DM yields of kale crops receiving 50 or 100 t ha^{-1} of compost were at least 11 t ha^{-1}. This is considered high for continuous dryland forage cropping in this area of South Canterbury, New Zealand (Andrew Kerr pers. comm., 2008). The increase in DM production between the 50 and 100 t ha^{-1} compost treatments was less in the first year than in the second. This may be attributable to an observed delay in emergence and a lower plant population in the 100 t ha^{-1} plots due to the blanketing effect of the surface-applied compost. Delays in emergence were not observed in the second kale crop because compost had been partly incorporated in the top soil through the action of livestock treading when grazing the first crop.

As well as increasing the DM yield of kale, compost improved feed quality in the first year. Results showed increases in the lipid, crude protein and ash content of the first kale crop grown after compost was applied. Application of compost had no effect on crude protein or ash concentrations in the second year, but the overall feed quality was higher than in the first year. The significant difference in crude protein concentrations between the two crops reflected the differences in available soil AMN to each crop. With lower AMN available to the first crop the crude protein responded to nitrogen released from the compost. Higher soil nitrogen would typically alter the plant structure to produce plants with greater stem biomass and this in turn can affect quality variables such as lipid and protein content. The second crop had higher AMN available at the beginning of the season and diminishing levels of N being released from the compost. Consequentially crude protein responses to rate of applied compost were no longer observed. Greater variability in soil physical properties and chemical fertility may also have contributed to the lack of quality effects in the second crop. This variability possibly resulted from the redistribution of nutrients from urine and dung across the treatments by grazing cattle, as well as extensive compaction of the soil surface in some areas caused by grazing the first crop under very wet conditions.

The higher DM crop yields and higher concentrations of soil AMN measured where compost was applied highlight the considerable amount of N released from the compost during the first 2 years. High soil N concentrations in the soil at the end of each crop suggest that significant savings could be made on fertiliser N inputs. The relatively high concentrations of mineralisable N measured in the control plots after the first crop compared with the baseline and second crop may be due to the shorter interval between when winter grazing was completed and soil sampling conducted (resulting in the urine and dung making a greater contribution to the mineralisable N measured). The extent of N mobilisation through the soil profile was not measured in this study but is an important consideration and is currently being investigated in an arable rotation compost trial at Lincoln, Canterbury.

As the organic C content of the compost when applied was 21%, the increase in soil C measured in the top 75 mm of soil in this study is likely to continue to be higher than in the control plots for several years as the compost decomposes from larger fragments to finer particles. Following a single application of compost, Sullivan *et al*. (2003) reported large and rapid increases in soil organic C that remained for 7 years (diminishing over time). The compost in this study was left on the soil surface and crops were direct drilled, hence the slight increase in organic C in the 75-150 mm depth with compost rate is likely due to the organic matter being incorporated in the lower depth following soil mixing associated with livestock treading and earthworm activity. The differences in organic C between the samplings can be attributed to the soil fine earth bulk density which was not affected by compost treatment but did vary between samplings. This was most evident following the second crop due to the bulk density being reduced by the sub soiling that occurred prior to crop establishment. This resulted in a reduction of organic C across all treatments at both the 0-75 and 75-150mm depths.

The higher concentration of soil organic matter in the compost treatments may have contributed to the improved water-holding capacity of the soil. In dryland farming, water demands can be high during summer and autumn. Improving the soil’s ability to hold water has important implications, especially for high-yielding crops like kale. This study showed that plots receiving compost held up to 9% more water than the control. For this particular soil type this equates to an increase in plant-available water from 17 mm in the control to 20 mm in the treated plots in the top 75 mm of soil. Results from this study support other research findings reporting improvements in soil organic matter concentration and water storage capacities following applications of compost (Greenwood *et al*., 1999; Khalilian *et al*., 2002).

The ideal pH for kale is between 5.8 and 6.2 (de Ruiter *et al*., 2009). The increase in soil pH measured in this study may have restricted the nutrients that are available to kale plants. Recent measurements of pH at this site confirm that pH is still elevated. An increase in soil pH following the addition of compost has also been reported by Paris *et al*. (1987) and Maynard (1995), although in both of these studies the compost was soil-incorporated.

While several previous studies (Maynard, 1995; Paris *et al*., 1987; Pearson *et al*., 1998; Sullivan *et al*., 1998) have shown marked improvements in the performance of crops fertilised with municipal compost, to our knowledge no studies have reported the effects of compost amendments on forage brassica crops. Furthermore, few studies have considered the effects of a single compost amendment on the performance of consecutive crops. Sullivan *et al*. (2003) found the greatest yield response during the second year after application of compost. They also reported measurable improvements in pasture DM production for the 7 years of the study following a single compost application of 155 t ha^{-1}. The aim is to continue this trial for another 3 years in order to better understand the longer term benefits of one-off compost applications in forage cropping system of New Zealand.

Conclusion

A single application of municipal compost (50-100 t ha^{-1}) to dryland forage crop systems resulted in significant improvements in the DM yield and quality of kale crops for 2 consecutive years. The results of this study to date suggest that the yield and quality effects of compost are most likely associated with an increase in the supply of plant available N and perhaps improvements in the storage of plant available water that help to reduce drought stress in dryland crops during the summer months. Continued measurements will enable the longer-term benefits of compost in forage rotations to be quantified.

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