The Use of Vegetable- and Bio- Waste Composts: Effects on Forage Maize Production and Soil Properties

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Abstract. Biodegradable municipal and farm waste compost application to agricultural land is increasing following the implementation of regulations which restrict the disposal of organic rich materials in landfills. Compost application, however, needs to ensure sustainable agricultural development. A field study was conducted on sandy loam soil to assess the agronomic benefit and the environmental risk from nitrate leaching following biowaste (containing kitchen, garden, paper and cardboard waste) and vegetable waste compost use in agriculture. The two composts were applied to forage maize production at three rates, ranging on average from 90 to 325 kg total N ha\(^{-1}\) yr\(^{-1}\). Mineral N fertilizer and non-amended soil was used for comparison. Forage maize response to compost application and mineral fertilization was limited in both years of application, as the soil itself met the N requirements of the crop, through the mineralization of soil inherent N. The monitoring of soil mineral N suggested that vegetable waste compost (C: N of 10.5) resulted in similar amounts of plant available N with mineral fertilizer N. Biowaste compost with C: N of 20 resulted in limited mineralization of compost N. In soils with high N mineralization potential applying biowaste compost resulted in lower risk of nitrate leaching. This study provided evidence to suggest that biowaste and vegetable waste compost use in agriculture can allow for the partial substitution of mineral fertilizer N.
and K. Following the repeated compost application in high rates, however, potential salinity or sodicity problems may rise.

**Keywords.** Forage maize, compost, nitrogen uptake, soil mineral nitrogen, salinity, sodicity
Introduction

Composting is promoted as an alternative to landfilling and incineration for the management of biodegradable waste (USEPA, 1994; CEC, 1999). Compost land application completes a circle whereby nutrients and organic matter which have been removed in the harvested produce are returned (Diener et al., 1993). Also, it contributes to the maintenance of soil organic matter and the reduction of soil erosion (Van-Camp et al., 2004). Further, it ameliorates soil, and partially replaces mineral fertilizers (Smith et al., 2001). However, the application of compost to soil could raise environmental risks mainly related to excessive or unbalanced supply of nutrients, introduction of heavy metals and organic pollutants (EC, 2003).

Compost utilization in agriculture needs to be carried out in a manner that ensures sustainable development, i.e. meeting crop nutrient requirements, whilst ensuring the protection of soil and water quality. It is important therefore to determine the fertilizer value and soil conditioning ability of compost and further to assess the risk of adverse environmental effects, such as water contamination from nitrate leaching. Most existing research has focused on animal manure and sewage sludge, whereas the investigation of biowaste and vegetable waste compost utilization in agriculture is limited. The objectives of this study were: (i) to assess forage maize yield and N availability to plants from a two years biowaste and vegetable waste compost application, (ii) to estimate the possible threats of compost use for excessive nitrate leaching and (iii) to evaluate the effect of compost type and application rate on soil chemical properties.

Materials and methods

Field experiment

The experiment was conducted in 2005 and 2006 on a sandy loam soil (68.6% sand, 19.4% silt and 12.0% clay) at the experimental farm of Cranfield University, UK. The site used to be grassland until 1980, when the grass was ploughed in the soil (0.2 m). Since 1980 to the beginning of the experiment the site had been used for the production of potatoes in 1990 and dahlias in 1991 and 1992. The weeds were ploughed in the soil annually (0.2 m). Some fertility parameters of the topsoil (0-0.3 m) at the beginning of the experiment are presented in Table1.

<table>
<thead>
<tr>
<th>pH</th>
<th>OM (%)</th>
<th>ECe (dS/m)</th>
<th>ESP (%)</th>
<th>Total N (%)</th>
<th>C : N</th>
<th>Mineral N (kg/ha)</th>
<th>Olsen P (kg/ha)</th>
<th>K (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7</td>
<td>3.01</td>
<td>0.8</td>
<td>0</td>
<td>0.12</td>
<td>10.4</td>
<td>54.6</td>
<td>369.7</td>
<td>944.0</td>
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</tbody>
</table>

The soil was amended with two compost types: (i) biowaste compost: produced from source-separated biodegradable municipal solid waste, containing food, garden, paper and cardboard waste, and composted in aerated vessels according to the animal by-products regulations, and (ii) vegetable waste (onion) compost: produced from onion waste mixed with straw and composted in uncovered static piles on-farm. The two composts were applied at three rates based on their total nitrogen (N) content. In the first year agronomic rates were used of 80, 165
and 250 kg total N ha\(^{-1}\). In the second year the rates were increased as follows: 100, 250, and 400 kg total N ha\(^{-1}\). The compost application rates along with the corresponding amount of nutrients applied each year are summarized in Table 2. The biowaste compost was surface applied and incorporated. The onion compost was only incorporated because of problems related to foul odor produced from the onion compost in the first year of the experiment, due to its low DM content (33%).

Table 2. Biowaste and onion comports: application rates and respective amounts of nutrients and organic matter (OM) applied per ha, and comports C: N ratio for the two years of the field experiment.

<table>
<thead>
<tr>
<th>Application rates (kg total N ha(^{-1}))</th>
<th>Fresh material (Mg ha(^{-1}))</th>
<th>Soluble mineral N (kg ha(^{-1}))</th>
<th>Soluble K (kg ha(^{-1}))</th>
<th>Soluble P (kg ha(^{-1}))</th>
<th>OM (Mg ha(^{-1}))</th>
<th>C: N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biowaste compost - 2005</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>80</td>
<td>9.4</td>
<td>1.3</td>
<td>32.8</td>
<td>1.2</td>
<td>2.1</td>
<td>16.2</td>
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<tr>
<td>165</td>
<td>19.0</td>
<td>2.6</td>
<td>66.0</td>
<td>2.4</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>29.6</td>
<td>4.0</td>
<td>103.0</td>
<td>3.8</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td><strong>Onion compost - 2005</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16.5</td>
</tr>
<tr>
<td>80</td>
<td>20.0</td>
<td>2.1</td>
<td>70.4</td>
<td>1.4</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>165</td>
<td>39.8</td>
<td>4.2</td>
<td>140.3</td>
<td>2.7</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>62.4</td>
<td>6.6</td>
<td>219.7</td>
<td>4.2</td>
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<tr>
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<td>7.9</td>
<td>2.0</td>
<td>47.6</td>
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<td>4.0</td>
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<td>19.8</td>
<td>5.0</td>
<td>119.0</td>
<td>5.0</td>
<td>10.1</td>
<td></td>
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<tr>
<td>400</td>
<td>31.7</td>
<td>8.1</td>
<td>190.4</td>
<td>8.1</td>
<td>16.1</td>
<td></td>
</tr>
<tr>
<td><strong>Onion compost - 2006</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.5</td>
</tr>
<tr>
<td>100</td>
<td>20.8</td>
<td>2.0</td>
<td>70.5</td>
<td>5.5</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>250</td>
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<td>5.0</td>
<td>176.3</td>
<td>13.7</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>83.4</td>
<td>8.0</td>
<td>282.1</td>
<td>22.0</td>
<td>8.4</td>
<td></td>
</tr>
</tbody>
</table>

Mineral N fertilizer was applied to separate plots in order to determine the N availability from the comports. In 2005, mineral fertilizer N was applied at 0 (control) and 80 kg N ha\(^{-1}\), whereas in 2006, it was applied at 0 (control), 40 and 80 kg N ha\(^{-1}\). Mineral fertilizer was surface applied after the crop sowing was completed. No mineral fertilizer was applied to plots which received comports in both years of the study. Each treatment was applied on an individual plot of 2.5m x 5m using a complete randomized block design with three replicates. Forage maize (Zea Mays L.) was used as the monitoring crop in both years. Crop sowing was at a rate of approximately 96000 seeds ha\(^{-1}\).
Crop and soil measurements and analysis

The effect of compost application to agricultural land was assessed by measuring crop and soil properties. Forage maize was harvested in both years once it had completed its physiological maturity and its dry matter content (DM) was about 30%. At harvest, crop above ground DM yield was determined by drying maize cobs at 60 °C until constant weight, and the rest of the plant at 105 °C for 26 hours. Maize total N concentrations were determined separately for the cobs and the rest of the maize plant by catalytic tube combustion using an elemental analyzer. The DM yield of maize cobs and of the rest maize plant were multiplied by the respective total N content, and then summarized to crop N uptake.

Soil quality properties were determined after harvest for the soil layer 0-0.3 m depth. The soil pH was determined in the 1/2.5 soil/water suspension, total N, total C and C: N ratio by the use of elemental analyzer. Available P was estimated by the Olsen method and measured by spectrophotometer. Extractable K and Na were extracted by ammonium nitrate and measured by flame photometry (MAFF, 1986). Soil salinity and sodicity were estimated by measuring the electrical conductivity in the saturated paste extract (ECe), and the exchangeable sodium percentage (ESP) from the sodium adsorption ratio (SAR) according to Richards (1954).

Soil ammonium (NH4) and total oxides of nitrogen (TON) -nitrogen fluctuations were monitored during the period of September 2005 to October 2006 within the top 0.6 m of the soil profile in the field. Below the 0.6 m depths there was sandstone. Samples were taken for the following soil layers: 0-0.3 m and 0.3-0.6 m. TON-N and NH4-N were measured in potassium chloride extracts by segmented flow analysis. The amount of soil residual TON-N after the crop harvest each year was used to estimate potential environmental threats due to excessive nitrate leaching. Analytical results expressed as concentrations were converted to kg ha⁻¹ assuming a bulk density of 1.44 g l⁻¹.

Statistical analysis

The effects of each treatment on the measured variables were assessed by analysis of variance (5% probability level) and the relation between variables was established by regression analysis (5% probability level) using the statistical package GenStat (GenStat, 2006).

Results and discussion

Forage maize dry matter yield and N uptake

Forage maize response to compost application and mineral fertilization was limited in both years of the experiment. Crop DM yield was not significantly affected (P>0.05) by compost or mineral fertilizer application in both years. The control soil resulted in 16 Mg ha⁻¹ DM yield in 2005 and 18.5 Mg ha⁻¹ DM in 2006. These values are in good agreement with forage maize DM yields reported for forage maize production with mineral fertilization at rates higher than 120 kg N ha⁻¹ (Pain & Phipps, 1974; Eriksen et al., 1999; Nevens & Reheul, 2003), which suggests that the soil itself was capable of providing the necessary nutrients for forage maize production, without any further fertilizer N or compost application to be necessary.

Figure 1 presents the forage maize N uptake in 2005 and 2006, in response to the different rates of compost and mineral fertilizer application. The differences between the treatments were
not significant (P>0.05) in both years of the experiment, suggesting that neither the application of composts, nor the mineral fertilization increased the crop N uptake significantly.

Figure 1. Forage maize N uptake (a) in the first year of compost application (2005), and (b) in the second year of compost application (2006) (■: Control, □: Mineral, ◆: Biowaste surface applied, ●: Biowaste incorporated, ▲: Onion incorporated).

The reason for this lack of response was attributed to the mineralization of soil inherent N and its utilization by the crop; the control treatment resulted in the same crop N uptake as the mineral fertilizers, indicating that the soil itself could cover the crop N requirements without any further N addition to be necessary. Net mineralization of soil inherent N during maize growing season was demonstrated in work by Richards et al. (1999), who showed a net N mineralization potential of about 140 kg ha\(^{-1}\) mineral N in different soils in the UK in the 7-10 weeks following maize drilling. Because of the lack of crop response, it was not possible to evaluate the N availability of compost N to the crop in both years of the experiment. However, the compost N mineralization patterns were estimated by monitoring the soil mineral N levels.
Soil mineral N

Soil NH₄-N was generally in low levels (less than 5 kg N ha⁻¹) during the monitoring period for all treatments. Only in September 2005, soil NH₄-N levels reached about 20 kg N ha⁻¹ for the control and the mineral fertilizer treatments, whereas the compost treatments were at levels lower than 10 kg N ha⁻¹. The differences between the treatments, however, were not significant (P>0.05). Soil TON-N was generally in higher levels compared to NH₄-N, ranging between about 15 to 180 kg N ha⁻¹ during the measuring period, thus indicating that this was the predominant form of mineral N in the soil profile of 0-0.6 m depths.

Figure 2a presents the soil TON-N levels after the crop harvest in September 2005. No significant differences (P>0.05) were observed for the different treatments within both sampling depths. The effect of compost application rate was found to be not significant (P>0.05). The decrease of TON-N concentration downwards the soil profile indicates low N losses by run-through and efficient N uptake by the crop during the growing season. Since all treatments were in the same levels with the control, excessive nitrate leaching during the winter was not expected from any of the different treatments.

The soil TON-N content was measured again in the middle of March 2006 (Figure 2b), in order to estimate possible nitrate leaching losses from the different treatments during the winter. The treatment ‘Mineral 40*’ at this stage of the experiment was the same as the control treatment; the second rate of mineral fertilization was applied for the first time in June 2006, after the crop sowing.

Comparing the Figures 2a and 2b it can be seen a decrease in the TON-N levels within the 0-0.3 m soil layer and a subsequent increase within the 0.3-0.6 m layer. Despite this downwards movement of TON-N throughout the soil profile, soil TON-N content of the 0-0.6 m depth remained at levels close to those measured in September and therefore no or limited leaching losses were expected to have occurred during winter.

Figure 2. Soil TON-N levels within the soil layer of 0-0.6 m depth measured (a) in September 2005, and (b) March 2006. Columns labeled with the same letter are not significantly different (P>0.05). (Inc: incorporated, Surf: surface applied; 40, 80: application rates in kg N ha⁻¹).
The effect of the compost application rate was found to be significant (P<0.05) in March 2006, with the lower rate (80 kg total N ha\(^{-1}\)) to result in significantly less soil nitrate-N content compared to the other two higher rates. The effect of compost application rate on soil TON-N content was not clear in any other sampling date. Petersen (2003) also found the effect of household waste compost application rate to be insignificant, over a three-year field experiment on sandy loam and loamy sand soil.

The next measurement of soil TON-N content took place in July 2006, about 1 month after the application of the composts and the mineral fertilizer (Figure 3). At this sampling date soil TON-N levels for all treatments were higher compared to the levels measured the previous two sampling dates. The high value of TON-N measured for the control soil indicates that these high TON-N levels were also supplied from the inherent soil N mineralization. This finding is in accordance with finding of Richards et al. (1999) who measured soil TON-N levels in different soil types in the UK, and supports the results of the high forage maize production from the control treatment.

The onion compost application resulted in significantly higher soil TON-N levels compared to the control and the biowaste compost treatments. This finding indicates higher N mineralization from the onion compost amended soil than the biowaste one. Onion compost resulted in similar levels of TON-N to the mineral fertilizer, thus suggesting the potential replacement of mineral fertilizer N by using onion compost.

![Figure 3. Soil TON-N levels within the top 0.6 m depths in July 2006. Columns labeled with the same letter are not significantly different (P>0.05). (Inc: incorporated, Surf: surface applied; 40-80: application rates in kg N ha\(^{-1}\)).](image)

The last measurement of soil TON-N was in October 2006, about 1 week after the crop harvest, in order to estimate the residual soil TON-N following two years of compost application (Figure 4). Figure 4 shows that both rates of mineral fertilization resulted in significantly higher residual soil TON-N content than the control, indicating that increased nitrate leaching losses was likely to occur during the following winter from the mineral fertilizer treatments. Both biowaste and onion compost amended soil resulted in similar levels of residual TON-N to the control, indicating that increased nitrate leaching should not be expected during the winter from the compost amended soil.
Figure 4. Soil TON-N content within the top 0.6 m depths in October 2006. Columns labeled with the same letter are not significantly different (P>0.05). (Inc: incorporated, Surf: surface applied; 40-80: application rates in kg N ha⁻¹).

The decrease of the soil TON-N content from July to October 2006 for all treatments shows the N utilization by the crop. However, leaching losses during the growing season might also have occurred, especially from the onion compost treatment. This can be derived from the difference of the soil TON-N content between the onion compost and the control treatments in July and October. Since the N uptake by the crop was similar for all treatments and the residual soil TON-N content in October was the same for the onion and control treatments, then the extra TON-N available in July in the onion compost amended soil is possible to have leached during the growing season, as it was in excess of the crop N requirements.

The control soil was capable of meeting the crop N requirements in both years of the field study, mainly through the mineralization of inherent soil N. Therefore the N applied by the mineral fertilizer and mineralized from composts was in excess to the crop N requirements and thus susceptible to leaching. Care, therefore, should be taken to adjust compost application so as the soil available N during the crop growing season does not exceed the crop N requirements.

TON-N levels of the biowaste compost amended soil were similar to the control throughout the monitoring period indicating limited mineralization of biowaste compost N. Hence, biowaste compost application, even to soils with N fertility, is not likely to increase N leaching, at least in the short term.

**Soil and compost N mineralization**

The total N content of the soil (within the top 0.3 m depths) was within common limits; total N content in sandy loam soils is reported to range between 0.10% and 0.15% (Chadwick et al., 2000; Nevens & Reheul, 2003; Chaves et al., 2005). The increased N mineralization observed during the study is associated with the low C: N ratio of the soil (C: N =10). Soil C: N ratio of 15 is suggested to be a critical limit separating soil groups with higher or lower N release (Springob & Kirchmann, 2003), thus supporting the high N release from our soil.
The high mineralization of the soil inherent N may be explained taking in consideration the history of the site, which involves plowing up grassland. Increase in N mineralization following plowing up grassland has been reported, especially the first years following the plowing. More N release is likely from grassland of increasing age (Johnston et al., 1994; Eriksen et al., 2006). Whitmore et al. (1992) showed that approximately 2000 kg N ha\(^{-1}\) were mineralized within the first 5.5 years following permanent grassland, whereas a total of 4000 kg N ha\(^{-1}\) were mineralized within 20 years. The increase in N mineralization, however, may persist for 25 years (Whitmore et al., 1992) or more than 27 years (Richter et al., 1989). The field, where this experiment took place, was permanent grassland and it was ploughed up in 1980. Since then it was left predominantly in fallow. The weeds grown were added back to the soil by annual plowing, hence possibly enhancing the easily mineralizable soil N. The low C: N ratio of the soil could indicate that soil N mineralization may persist for more years.

The second year of the field experiment has shown evidence of lower mineralization of biowaste compost N (C: N of 20.1), in comparison to onion compost N (C: N of 10.5). In addition, the TON-N content of the biowaste compost amended soil was in similar levels to the control soil, during the monitoring period, thus indicating that biowaste compost N mineralization was limited. These results indicate that compost with low C: N ratio can partially replace mineral fertilizer N, whereas compost with C: N higher than 20 should not be considered as mineral fertilizer N supplement. They also support results from other work showing that organic materials with C: N ratio lower than 15 are likely to result in net N mineralization (Jimenez & Alvarez, 1993; Chadwick et al., 2000; Gutser et al., 2005).

Other soil properties

The two years of compost application had limited influence to most soil properties. The following properties were not significantly affected (P>0.05) by the compost application: pH, total N, total C, C: N ratio and extractable P.

In the second year of compost application, the onion compost significantly increased soil K content compared to the biowaste and the control (P<0.05). The increase of compost application rate significantly increase soil K content (P<0.05). The reason why the onion compost resulted in higher soil K levels was related to the higher amounts of soluble K applied by the onion compost in both years of the study (see Table 2). There was a linear relationship between compost K added in both years of the study and the soil K levels in 2006 (r = 0.791, P < 0.001).

The two years of compost application resulted in significant increase (P<0.05) of soil extractable Na content, as shown in Figure 5. Onion incorporated and biowaste surface applied composts at rates lower than 250 kg total N ha\(^{-1}\) in 2006, did not increase significantly (P>0.05) the soil Na levels compared with the mineral fertilizer. The incorporation of biowaste compost even at the lowest rate significantly increased (P<0.001) soil Na in comparison with the reference treatments.

Considering a given rate of application, the biowaste compost applied on the soil surface and the onion compost incorporated resulted in similar levels of soil Na (P>0.05). With the exception of the lowest application rate, the biowaste compost incorporated resulted in significantly (P<0.05) higher soil Na than when surface applied. This finding indicates that the surface application of the biowaste compost resulted in lower availability of compost Na.
The effect of compost application rate was observed to be significant. The increase of the compost application rate resulted in significant increase (P<0.001) of the soil Na content. Soil Na content increased linearly with the addition of higher amounts of compost Na (r = 0.925, P < 0.001), when biowaste or onion compost was incorporated.

The increase of the soil Na content following the compost application may raise problems with soil salinity and sodicity, especially in a year-after-year application regime. After the first year of compost application the soil ECₐ was not influenced by the different treatments. The average for all treatments was equal to 0.5 dS m⁻¹. The soil ESP was zero for all treatments. After the second year of compost application, the analysis of the high application rates of the different treatments showed that compost application and mineral fertilization significantly increased soil ECₐ (P<0.05). The onion compost resulted in the highest soil ECₐ (P<0.10), which was equal to 1.4 dS m⁻¹, while the control was 0.6 dS m⁻¹. An ECₐ value of 1.4 dS m⁻¹ is below the limit of 4 dS m⁻¹ which is critical for most crops. However, this result may indicate potential salinity problems following year-after-year compost application at high rates.

Soil ESP was significantly increased (P<0.05) by biowaste compost incorporation only. The ESP of the control, onion and mineral fertilizer treatments remained equal to zero. Despite the increase in ECₐ following onion compost application, soil ESP did not increase, indicating that the increase in ECₐ was predominantly due to the increase in other nutrients than Na, e.g. TON and K; hence suggesting that onion compost application improved the nutrient status of the soil. The incorporated biowaste compost resulted in ESP equal to 0.4%, whereas the surface applied biowaste to 0.1%, which are both very low ESP values, considering that the ESP limit for sodicity problems is 15%. Despite that, these results indicate that soil salinity and sodicity should be monitored when composts applied to agriculture in consequent years to avoid deteriorating soil quality. Increased levels of soil EC due to compost application have been reported by Stamatiadis et al. (1999) and Madejón et al. (2001). They also concluded that although the increase of ECₐ was not found capable of causing a sodium hazard to the soil, it indicated potential problems following the repeated application of compost to agricultural soil.

Figure 5. Soil extractable Na levels as affected by the different treatments (■: Control, □: Mineral, ◇: Biowaste surface applied, ●: Biowaste incorporated, ▲: Onion incorporated).
Conclusions
The conclusions drawn from the field study can be summarized as follows:

1. Biowaste and onion compost application had no significant effect on forage maize yield and N uptake, mainly due to the mineralization of background levels of soil inherent N and its utilization by the crop.

2. Compost C: N ratio influenced N mineralization. Onion compost with C: N ratio of 10.5 resulted in higher levels of soil mineral N than the biowaste compost with C: N of 20.1 during the crop growing season, indicating the higher N fertilizer potential of composts with lower C: N ratio.

3. High rates of compost application increased soil extractable K levels, thus increasing soil fertility and reducing the mineral fertilizer K requirements for crop production.

4. Consecutive biowaste and vegetable waste compost application to agricultural soils in high rates is likely to result in salinity and/or sodicity problems in sensitive soils (such as heavy soils, or coastal areas), or reduced yields of salinity sensitive crops.

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