RESEARCH SUB-PROGRAM

APPLICATION OF COMPOSTED ORGANIC WASTE TO AGRICULTURAL LAND

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FORWARD

This report is one of a series of **COESA** (Canada-Ontario Environmental Sustainability Accord) reports from the Research Sub-Program of the Canada-Ontario Green Plan. The **GREEN PLAN** agreement, signed Sept. 21, 1992, is an equally-shared Canada-Ontario program totalling $64.2 M, to be delivered over a five-year period starting April 1, 1992 and ending March 31, 1997. It is designed to encourage and assist farmers with the implementation of appropriate farm management practices within the framework of environmentally sustainable agriculture. The Federal component will be delivered by Agriculture and Agrifood Canada and the Ontario component will be delivered by the Ontario Ministry of Agriculture and Food and Rural Assistance.

From the 30 recommendations crafted at the Kempenfelt Stakeholders conference (Barrie, October 1991), the Agreement Management Committee (AMC) identified nine program areas for Green Plan activities of which the three comprising research activities are (with Team Leaders):

1. **Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes** through land application, with emphasis on water quality implications
   A. Animal Manure Management (nutrients and bacteria)
   B. Biodegradable organic urban waste application on agricultural lands (closed loop recycling)
   (Dr. Bruce T. Bowman, Pest Management Research Centre, London, ONT)

2. **On-Farm Research**: Tillage and crop management in a sustainable agriculture system. (Dr. Al Hamill, Harrow Research Station, Harrow, ONT)

3. **Development of an integrated monitoring capability** to track and diagnose aspects of resource quality and sustainability. (Dr. Bruce MacDonald, Centre for Land and Biological Resource Research, Guelph, ONT)

The original level of funding for the research component was $9,700,000 through Mar. 31, 1997. Projects will be carried out by Agriculture and Agri-Food Canada, universities, colleges or private sector agencies including farm groups.

This Research Sub-Program is being managed by the Pest Management Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford St., London, ONT. N5V 4T3.

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APPLICATION OF COMPOSTED ORGANIC WASTE TO AGRICULTURAL LAND

FINAL REPORT

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Agriculture and Agri-Food Canada
Canada-Ontario Agriculture Green Plan

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EXECUTIVE SUMMARY

The application of composted organic waste to agricultural lands has the potential to benefit agriculture in terms of improving soil quality, but information on the environmental and agronomic aspects of the use of compost is needed to allow farmers to assess the risks and benefits of its use. The purpose of this study was to evaluate the impact of composted organic waste applications to farmland on soil quality, crop growth and yield, and water quality in addition to assessing the economics of its application.

A series of laboratory and field experiments were conducted over a four year period to determine the feasibility of applying urban generated compost to farmland for crop production. Sites for the field trials were established on loam and clay loam soils on farms near Campbellville, Ontario. The finished composts used in the trials were a mixture of food, wood, paper and yard waste sources, and were obtained from two private composting facilities.

The yields of corn, soybeans, and all-grass hay were not generally depressed by the addition of compost. In fact, in some cases significant increases in production were attributed to compost. Incorporation of the compost was not demonstrated to be necessary.

Clear evidence of altered nitrogen availability was not demonstrated and it appeared that normal nitrogen application rates would be required in conjunction with the compost applications. The contribution of nitrogen mineralized from compost was not significant in this study.

Lettuce seed germination in sand-compost mixes in the lab indicated that high concentrations of compost in the mix and pure composts were not suitable for seed germination. Mixes containing less than 25% compost by weight were unlikely to inhibit germination provided that the composts were relatively biologically stable, or 'finished'. Such a phytotoxic effect of the composts may explain the clear preference for fall applications of compost by both corn and soybeans which was evident in a single year trial comparing rates and time of application. However, the effect was most noticeable at rates of greater than or equal to 150 Mg (wet) compost ha^{-1}. The spring applications of compost in other trials in this study often improved crop success over that where no compost was applied.

Compost improved soil quality by raising the soil test index, thus reducing the requirement for phosphorus, potassium, and zinc. However, the two compost sources varied in their ability to elevate soil test levels in relation to the amount of total P they contained. Substantial increases in the organic carbon content of the soil were evident after only three years of applying the compost on both soils.

The higher organic carbon level in the soil, in turn, was related to a decrease in soil density with a corresponding increase in total porosity. A greater infiltration rate resulted from the increased porosity. A higher residual pore volume and increased water retention was observed for one of the composts.

After three successive years of compost application the metal content of the surface soil was not increased to levels of potential concern. Evidence of potential nitrate nitrogen contamination of ground water supplies was not found. Only sporadic indications of a few metals (Cu, Mn, Ni, Zn) in the water percolating through the soil profile were observed. Where they appeared they were not always associated with a compost treatment.

Some of the parameters measured were influenced to varying degrees by the source of the compost; a result of differing analysis of the two materials used in the experiments.

An economic analysis of the use of urban compost on agricultural land indicated that the value to the producer through yield and enhanced soil fertility would barely cover the application costs if the compost were delivered to the farm site at no cost. However, since benefits of compost application to the soil have been demonstrated which were intangible, such as organic carbon and increased porosity, a farmer could justify the cost of applying the material if it were delivered free to the farm site.

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1. INTRODUCTION

Compost is defined as "the material produced by an aerobic composting process, which can be used as a soil amendment, or for other similar uses. Simple exposure of solid organic waste under non-engineered conditions resulting in uncontrolled decay is not considered to be composting..." (Ontario Ministry of the Environment, 1991).

In Ontario, aerobic compost operating practices and compost quality are outlined in the Interim Guidelines for the Production and Use of Aerobic Compost in Ontario (Ontario Ministry of the Environment, 1991). Compost quality is defined by its content of metals (As, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, and Zn), organic chemicals (PCB's), non-biodegradable particulate matter (plastic and other), and its biological stability. Compost failing to meet the guidelines is considered as waste while compost which meets the guidelines is deemed a product with no restrictions on its use.

Biological stability does not have an exact definition with respect to composting (OMOE, 1991). Under proper composting conditions, it is proportional to retention time and waste characteristics. The degree of stability required by a compost may vary depending on its end use. Complete stability is not readily attainable and is considered undesirable since a completely stable product would not lend amending value to the soil (OMOE, 1991). On the other hand, compost with a high potential for continuing decomposition may produce toxic effects in crops and immobilize nitrogen. Tests such as oxygen uptake rates, toxin production, C:N ratios, and seed germination and growth tests, are among the determinants of the relative stability of the compost.

Composted organic wastes are considered to be soil amendments for agricultural purposes. The compost may improve soil structure and water holding capacity and provide soil nutrients. The analysis of compost materials varies according to the source waste and the method of composting. The behaviour of the compost in soil has been shown to vary as well, depending, for example on the particle size which relates to the pore size within the material (Goldstein, 1988). In the Green Plan Ag Stakeholder's Forum, a participant identified the "need to assure the farmer what the nutrient content in the material is and to reinforce the business of food safety..." in order to develop the "workable flow of organic wastes/resources in a closed-loop that will take organic material from the urban sector back to the agricultural part of the community." (Soil and Water Conservation Information Bureau, nd).

An evaluation of the effects of composted sewage sludge and composted paper waste application to soils in Ontario was conducted by Baldwin *et al.* (1989). The consequences of a one time application of the materials to Fox sandy loam and Brookston clay loam on corn production were assessed over a five year period. Fall applications of the materials ranged from 55 to 220 tonnes ha^{-1}. Compost application caused difficulties in seedbed preparation in the spring on the clay loam soil which was attributed to the compost preventing the soil surface from drying out. Composted materials did not generally influence the growth and yield of nitrogen fertilized corn. An immature composted paper waste application resulted in stunted and chlorotic corn plants and reduced grain yields at one site where applications were greater than or equal to

110 T ha^{-1}. The toxic effect was attributed to the short curing time of the compost (ie. its stability). While no impacts of the compost on metals (As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se, and Zn) in corn leaves and grain were evident, soil Cu and Ni levels were increased.

Over the five years, increases in soil organic matter were detected at the clay loam site. Increases were related to increasing compost application amounts. Changes in organic matter in the sandy loam were less consistent. Soil bulk densities were not affected by compost additions. Compost applications generally increased soil phosphorus levels.

The findings by Baldwin *et al.* (1989) are consistent with observations in another study which compared several types of compost. A yard waste/sludge compost mixture induced nitrogen deficiency in lettuce and carrots despite its having similar physical and chemical characteristics as sludge compost as well as a higher N content and more favourable C:N ratio (23:1 vs 36:1) (Henry and Harrison, 1992).

Where nitrogen fertilizer supplemented compost additions, higher yields of corn were associated with the addition of up to 2228 tonnes ha^{-1} in total in five consecutive years of application of (446 tonnes ha^{-1} yr^{-1}) municipal waste compost (Mays and Giordano, 1989). Increases in corn yields due to compost were observed "routinely" over a 14 year period. Fifteen years after the last compost application had been made, physical properties of the soil were measured. Water holding capacity had increased and bulk density had decreased where high total rates of compost had been applied. Heavy metals (Cd, Cu, Pb, Ni) in the surface soil were correlated with the amount of compost applied but virtually no movement of metals below 30 cm was detected.

Other effects of composted materials include beneficial effects on the number and functions of heterotrophic N-fixers and vesicular-arbuscular mycorrhizae (VAM) (Jodice and Nappi, 1987), and in control of plant diseases (Hoitink, *et al.*, 1987).

In general, compost products are used more in residential, nursery, and landscape applications, than in agriculture (Eggerth, *et al.*, 1989; pers. comm. with compost producers). Limitations to the use of composts in agriculture include the cost of transportation and the cost of application (Eggerth, *et al.*). Markets for compost were considered to be affected by consistent quality, availability, and user understanding of the benefits and/or limitations of the three products used in the market analysis study (Eggerth, *et al.*, 1989).

In summary, compost additions to soil can alter both water retention characteristics and soil chemical properties. In the long term, after several years of compost application the changes in soil properties have been evident. The behaviour of many compost materials in soils, however, is not predictable. The understanding of the benefits and limitations of compost use and the costs of transportation and application appear to be constraints on the adoption of its use in agriculture.

The research subprogram of the Canada-Ontario Green Plan was designed to encourage and assist farmers with the implementation of appropriate farm management practices within the framework of environmentally sustainable agriculture. The Green Plan research activities were designed to promote reduced tillage and improved soil quality in the context of sustainable agriculture.

The research was designed to achieve a balance of objectives in terms of productivity, environmental filtering and partitioning of water. The research must also produce tangible deliverables within the five years which are directly applicable at the local farm level.

The objectives of this study on composted organic urban waste application to agricultural lands were to evaluate the impact of the composted products on soil quality, crop growth and yields, and on water quality. An additional objective was the evaluation of the economic impacts of its application on farming operations.

Through field studies an attempt was made to address the following questions concerning compost use in agriculture:

- how does compost type and the degree of incorporation into the soil (incorporated or not) influence the water balance early in the season, following its application;
- what products of compost decomposition migrate in the soil profile and potentially reach groundwater supplies;
- what are the implications for soil erosion and runoff water with compost application;
- how does compost application influence the emergence, growth, and yield of field crops;
- what is the influence of the compost additions on soil biology;
- what are the intermediate term (3 year) effects on soil physical properties such as water holding capacity, and aggregate stability;
- what are the costs and benefits associated with the use of compost on agricultural land;
- what are the farm practices in relation to compost type and quality that can be recommended and applied at the field level;
- how does compost application reconcile with the concepts of reduced tillage; and
- what are the probable agronomic and environmental implications of long-term farm level use of composted materials and what future studies need to be conducted to ensure that the practice is sustainable and can be managed and self-regulated by the farmer.

The report describes studies carried out on the laboratory bench to compare compost sources and to observe their properties in seed germination and emergence tests (Section 2); two field trials carried out at one site in a single year to examine effects of compost rates and timing of application on crop production (Section 3); a single year trial evaluating the effects of compost on grass hay yields and nitrogen use efficiency (Section 4); and the main trial (Section 5) in which the effects of successive annual applications of two compost materials and at two farm sites are evaluated based on their effects on soil and crop parameters.

The interpretation of the studies in terms of the objectives is discussed in Section 6 and summarized in Section 7.

2. BENCH TOP STUDIES

2.1 Introduction

A series of tests were conducted on the laboratory bench in order to compare effects of compost materials on seed germination or plant emergence (Section 2.2, 2.3, 2.4) and to evaluate effects of management of the materials on seedling emergence and early growth (Section 2.4, 2.5).

To compare composts from various sources, materials were collected from composting facilities in December 1993-January 1994. The materials included: a leaf compost (Gu), two food and yard waste composts (Sc and Lc), and a corn and bean cleaning plant compost (He). The He compost was unfinished, having undergone only 2 months of curing while all other materials were considered to be finished.

An analysis of the materials is provided in Appendix A.1. The leaf compost (Gu) was high in Ni and Pb, relative to compost guidelines. The unfinished He compost contained relatively high ammonium concentrations. Electrical conductivity of the unfinished material (He) and the food and yard waste compost (Sc) exceeded typical levels defined by MOEE's draft compost guidelines (OMOE, 1991).

2.2 Lettuce Seed Germination in Compost-Sand Mixes

2.2.1 Objective

Ë to test the toxicity of compost materials on the germination of lettuce seeds.

2.2.2 Methods

The methods used were adapted from the EPA protocols for short term toxicity screening of hazardous waste sites (Green *et al.*, 1989). Compost was mixed by weight with washed silica sand. Mixes were: 100, 50, 25, 12.5, 6.25, and 0 % compost. 100 g of each air dried compost-sand mix was placed in 150 mm (diameter) glass petri dishes. Twenty lettuce (*Lactuca sativa*) seeds were placed on the mix in each dish, pressed in to the surface, and covered with 40 ml of sand. Water was added to the test material. The mixes were watered to 85% of their water holding capacity as determined prior to the tests. Lids were placed on the dishes which were then placed in resealable plastic bags. The bags were placed in an incubation room for 120 hours at 21EC. The incubation was under an initial dark period of 48 h followed by 16 h of light and 8 h dark. At the end of the incubation period, the number of seedlings protruding above the surface in each dish were counted.

2.2.3 Results

The average number of seeds germinated was 14.6, or 73%, in the pure sand mixes (n=12). According to Green *et al.* (1989), mean germination in controls using an artificial soil should be at least 90% to be acceptable. The pure sand may not have had optimum conditions for lettuce seed germination.

The number of seeds germinated declined with increasing amounts of compost in the mix (Table 1). Linear regression produced negative slopes for Sc, Lc, and Gu compost, though the linear relationships were not significant except for Sc and did not explain much of the variability in germination, with R^2 values less than 0.3 (see Appendix A.3). Low germination of seeds at the 100 and 50% compost mixes in one replicate decreased means for these two rates.

Table **1.** **Percent of Seeds Germinated in Compost-Sand Mixes after 5 days**

Fraction of compost in mix	Compost Source			
	Gu	**Sc**	**Lc**	**He**
0	73.3	68.3	71.7	78.3
0.0625	90	88.3	90	36.7
0.125	88.3	85	90	21.7
0.250	75	90	66.7	11.7
0.500	58.3	56.7	50	0
1.000	50	46.7	56.7	0
Mean	72.5	72.5	70.8	24.7

The He compost mixes fit an exponential (p=0.0035; R^2=0.676) curve (Figure 1). No seeds germinated from the 50% and 100% mixes of He compost in all of the replicates. Evaluation of the exponential relationship

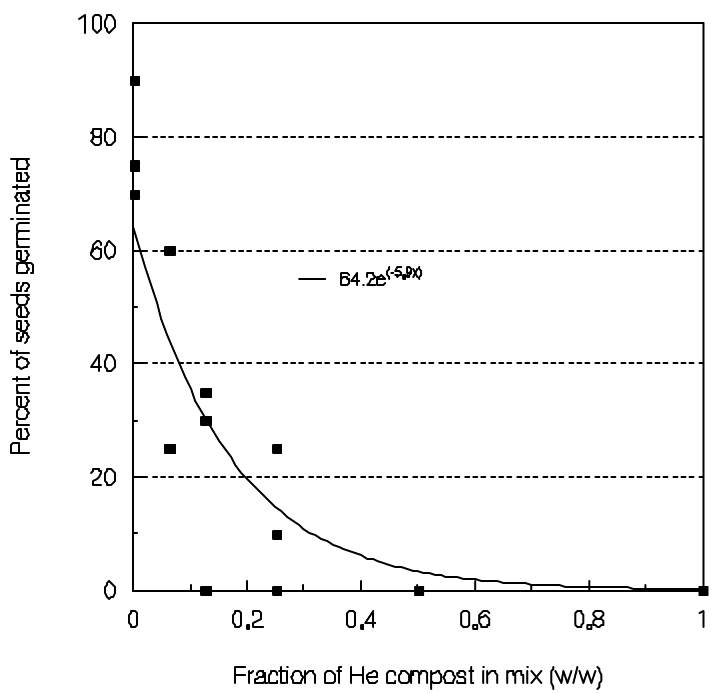

Figure 1. Lettuce seed germination after 5 days in the He compost-sand mix.

indicates that 50% of the seeds would fail to germinate where the He compost comprised 3% of the mixture by weight.

2.3 Lettuce Seed Germination in Compost Elutriate

2.3.1 Objective

Ë to test the relative toxicity of leachable compost materials on the germination of lettuce seeds.

2.3.2 Methods

The methods used were adapted from the EPA protocols for short term toxicity screening of hazardous waste sites (Green *et al.*, 1989). A compost elutriate was prepared by mixing 375 g of air dry compost from each of the four compost materials with deionized water in a ratio of 4:1 water:compost. The mixture was shaken for 48 hours and the liquid separated from the solid fraction by centrifuge. The elutriate was analyzed for metals - Mn, Cu, Zn, Ni, Co, Cd, Cr, Pb - nitrate, nitrite, ammonium, pH, electrical conductivity, total coliforms and E. coli. Analysis was carried out by Analytical Services Laboratories except for total and fecal coliforms which was carried out by the Ontario Ministry of Health Laboratory Services.

The elutriate was diluted to various concentrations with deionized water: 100, 50, 25, 12.5, and 6.25% (v/v). Filter paper was wetted with 5 ml of solution in a plastic petri dish. Twenty seeds were placed on top of the paper. The dishes were covered and placed in the dark for 5 days, following which the number of seeds with a root or shoot emerged was counted. Three replicate dishes were prepared for each solution. A control consisted of deionized water.

2.3.3 Results

Compost Elutriate

The compost elutriates had pH in the range of 7.1 to 8.0. For comparison with the elutriates, the characteristics of irrigation waters are shown with the elutriate analyses (Appendix A.2). Water meeting the irrigation water guideline concentrations will normally not adversely affect plants or soils. The compost elutriates were largely within the guidelines for use in agriculture for irrigation (Ontario Ministry of Environment, 1984). Electrical conductivity of the Sc and He materials were elevated relative to the other materials. All the compost elutriates have the potential, based on their electrical conductivity values, to cause crop damage if used for irrigation (OMOE, 1984). E. coli levels were less than 10 colonies/100mL, well below standards set for swimming water, of less than 100 colonies/100mL

Seed Germination

The average number of seeds germinated in the control treatment was 17, or 85%, and was the same for all three replicates.

The elutriate prepared from the Gu, Lc and Sc composts produced no effect on seed germination. The average of these compost sources had germination levels at least equal to the average of the control (Table 2).

Increasing concentration of elutriate from the He compost reduced germination of the seeds. The undiluted He elutriate resulted in only 27% germination. The relationship between elutriate concentration and germination was described by a quadratic equation where both coefficients had negative values ($P<0.001$,

R^2=0.948) (Figure 2). According to this relationship half of the seeds would not germinate at a concentration of 75% elutriate.

Table **2.** **Percent of Seeds Germinated in Compost Elutriate Preparations after 5 days**

Concentration of Elutriate	Compost Source			
	Gu	**Sc**	**Lc**	**He**
0	85			
0.0625	91.5	91.5	91.5	90
0.125	91.5	90	88.5	78.5
0.250	91.5	88.5	90	85
0.500	88.5	91.5	85	66.5
1.00	86.5	90	85	26.5
Mean	90	90.5	88	69.5

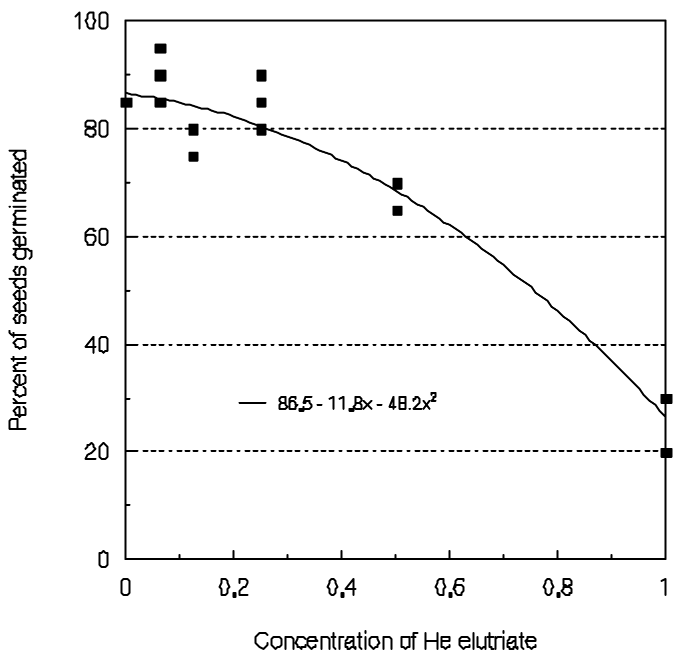

Figure 2. Lettuce seed germination after 5 days in the He compost elutriate**.**

2.4 Effect of Compost Type and Application Rate on Emergence of Corn

2.4.1 Objective

Ë to establish the effect of depth of several soil surface applied compost materials on the emergence and early growth of corn.

2.4.2 Methods

A mixture of 75% Colwood silt loam and 25% fired clay (Turface) was placed in compartments of plywood boxes. Each compartment measured 12 cm (w) x 27 cm (l) x 14 cm (h). Soil was added to varying depths within the compartments so that when the compost was added, the compartments would be filled to the height of the compartments. Twenty corn (*Zea mays* cv Dekalb 331) seeds were planted in two rows running the length of the compartment, a uniform 5 cm depth of soil mix was added, and compost was added to depths of 0.0, 1.3, 2.5, 3.8, and 6.4 cm. The composts used were those described in Section 2.1. The 1.3 cm rate equated to an 82 to 116 Mg ha^{-1} wet weight. The highest rate, of 6.4 cm, equated to 321 to 479 Mg ha^{-1} (see Appendix A.4 and A.5).

The wet weight of compost added was recorded and a compost sample dried at 70EC for moisture determination. Water was added to compartments at 500 ml plus 50 ml per 1.3 cm of compost depth applied in order to ensure adequate moisture. Holes were provided in the bottom of the boxes to allow for drainage.

The boxes were covered with plastic film until the seeds emerged, and were kept in the lab at room temperature; approximately 20EC. Number of seeds emerged were recorded at 5, 6, 7, and 8 days (E5, E6, E7, E8, respectively) from planting. At the end of the experiment, 12 days after planting, all plants were cut at the soil or compost surface, dried, and weighed.

The experiment was a factorial, with 5 rates of compost, and 4 compost sources. The trial was repeated three times. After each trial, the compost was removed and discarded, the soil mix was removed from the boxes, the corn seeds were removed and discarded, and the soil was screened and reused. Results of the statistical analysis appear in Appendix A.6.

2.4.3 Results

Effects of compost depth

The number of seeds that had emerged 5 days after planting (E5) was variable. Emergence was significantly slowed at compost depths of 3.8 and 6.4 cm (Table 3). One day later (E6), however, emergence was more uniform but the 6.4 cm depth remained significantly behind other treatments, with 65% fewer seeds emerged than the control. This trend continued until E8 when the effect of depth of application of compost was insignificant for all depths ($P = 0.114$). An average emergence of 87% was achieved by E8. The control treatment had higher average emergence at each date but the difference in emergence between the control and the 6.4 cm depth at E8 was only 8%.

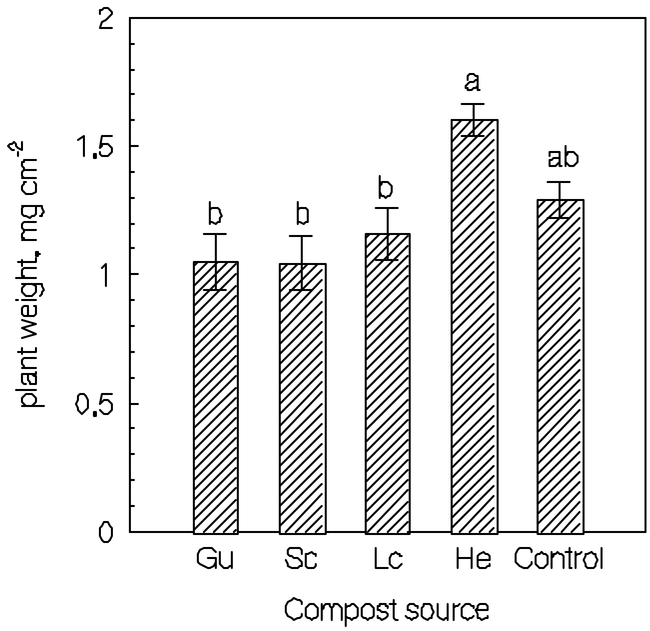

Figure 3. The average effect of compost source on corn plant weights measured 12 days after planting (error bars shown).

Table **3.** **Effects of Compost Depth on Emergence of Corn**

Depth, cm	**% Emerged at Days after planting**			
	5	**6**	**7**	**8**
0	82	88	88	90
1.3	64	82	85	85
2.5	51	79	86	88
3.8	34	78	86	88
6.4	16	57	77	82

The amount of corn dry matter accumulation at E8 did not follow the emergence pattern. It appeared that corn growth, as measured by dry weight at eight days, was maximized under a 2.5 cm compost application and was significantly impeded by a 6.4 cm compost application (Figure 3).

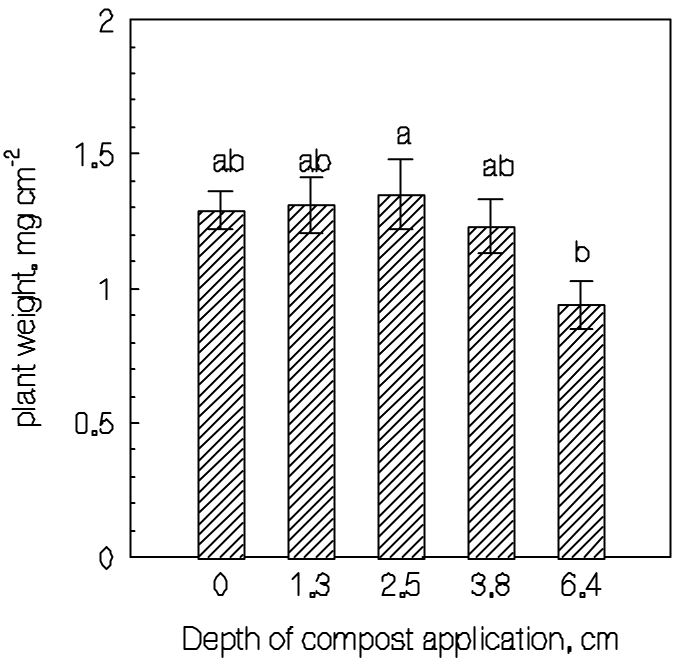

Figure 4. The average effect of compost depth on corn plant weights measured at 12 days after planting.

Effects of compost source

The He compost produced similar emergence as the control at E5, while the other three compost sources had a much lower number of plants emerged (Table 4). By E6 emergence of plants through Gu leaf and Sc food and yard waste compost was still less than the control. Effects of compost source were not significant at E7 and E8 although the mean emergence remained numerically greater in the control than where compost was applied.

Table **4.** **Effects of Compost Source on Emergence of Corn**

Source	**% Emerged at Days after planting**			
	5	**6**	**7**	**8**
Gu	25	69	83	87
Sc	26	71	82	86
Lc	36	72	83	86
He	79	84	85	85
Control	81	88	88	90

Again, the effect of compost source on plant weights followed a pattern different from that of the emergence (Figure 4). Corn plants under the He compost had a greater dry matter accumulation than all other compost sources.

2.5 Effect of Compost Application Rate on Emergence of Soybean

2.5.1 Objective

Ë to establish the effect of the depth of a surface applied compost on the emergence and early growth of soybeans.

2.5.2 Methods

The methods and equipment used in this study were identical to those described in Section 2.4.2 with the exception that twenty soybean (*Glycine max* cv OAC Shire) seeds were planted in two rows running the length of the box. Then the soil mix was added to a depth of 2.5 cm above the seeds and the compost applications were made so that the compartments would be filled to the height of the compartments. Four replications of five depths of compost was added, 0.0, 1.3, 2.5, 3.8, and 6.4 cm (0.0, 0.5, 1.0, 1.5 and 2.5 inches, respectively). Seeds were planted March 10, 1995. Since the field experiment (Section 3) involving soybeans used the Sc compost, the Sc food and yard waste compost was used in this experiment.

The wet weight of compost added was recorded and a compost sample dried at 70EC for moisture determination. The 1.3 cm rate equated to a 68 Mg ha^{-1} wet weight. The highest rate, of 6.4 cm, equated to 314 Mg ha^{-1} (see Appendix A.7). These rates are lower than those achieved using the same compost source in a similar experiment using corn seeds in 1994 (see Section 2.4).

Water was added to compartments equivalent to 900 ml on March 10 and an additional 500 ml was added on March 13 in order to ensure adequate moisture.

The boxes were covered with plastic film until the seeds emerged. They were kept in the lab at room temperature. The number of seeds emerged were recorded at 5, 6, 7, 10 and 12 days (E5, E6, E7, E10, E12 respectively) from planting. At the end of the experiment, all plants were cut at the soil or compost surface, dried, and weighed.

2.5.3 Results

Emergence and Plant Dry weights

Five days after planting, 68% of the soybeans planted had emerged where no compost was applied, 25% had emerged at the lowest rate of compost, whereas none had emerged under any of the higher rates (Table 5). By ten days after planting (DAP), however, soybeans had emerged under all compost depths. By 12 days after planting, only the highest rate contained significantly fewer number of emerged plants.

Table **5.**	**Effects of Compost Depth on Emergence of** Soybean				
Depth, cm	**% Emerged at Days after planting**				
	5	**6**	**7**	**10**	**12 ‡**
0	68	81	84	84	85 a
1.3	25	59	70	81	85 a
2.5	0	19	54	78	78 ab
3.8	0	0	9	60	64 ab
6.4	0	0	0	25	48 b

‡ means within this column followed by the same letter are n.s. different at P#0.05

Soybean plant weights similarly indicated that significant negative impacts on plant growth are evident only at the highest rate of compost application (Figure 5).

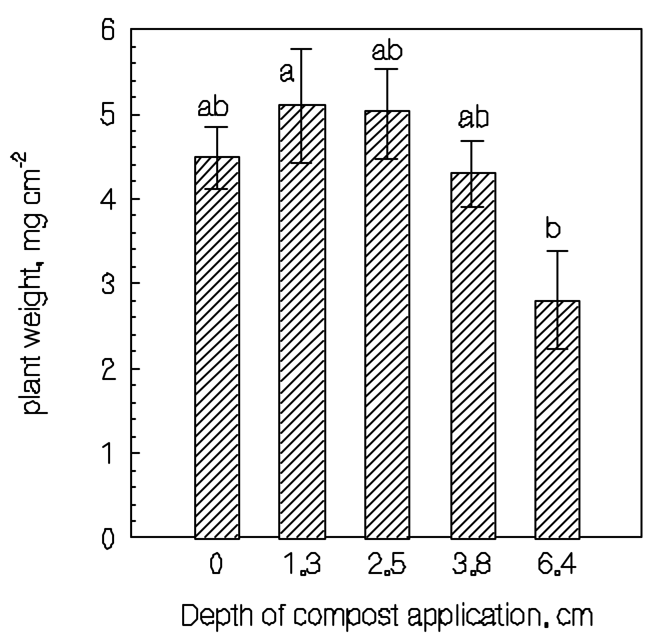

Figure 5. Effects of Sc compost application rates on soybean plant weights measured at 12 days after planting (standard error bars shown).

2.6 Summary of Bench top Studies

Results of the germination tests suggest that the unfinished He compost material, with only two months of curing, inhibits germination, particularly when in contact with the seed as in soil mix or as elutriate. Where the unfinished compost was surface applied to soil in which corn seed was planted, however, the effects of the unfinished compost on early growth were positive, presumably due to readily available NH_4^+-N.

The finished compost materials - Sc and Lc food and yard waste, and Gu leaf waste - did not appear to be toxic to lettuce seed germination in the germination tests carried out using the extracted solutions. On the other hand, the tests using sand-compost mixes suggested that high contents of compost and pure compost are not suitable for seed germination, because in these tests, the seeds were exposed to more concentrated compost solutions. Using the compost and compost-sand mixes, water was added to 85% of water holding capacity. The ratios of water:dry compost amounted to 0.73 to 1.1 in the four different pure composts. Under these conditions, seed germination was inhibited. The compost elutriates were prepared using a 4:1 water:compost. This ratio compares to that which would exist in the solids mix comprising 6.25% compost. Generally, it appeared that only mixes containing less than 25% finished compost by weight could be used to successfully establish lettuce seedlings.

The tests involving surface applications of compost suggest that compost may slow initial corn emergence but that only very high rates (6.4 cm) are likely to reduce final emergence and growth.

Similarly, while even low surface application rates of compost may slow initial soybean emergence, only very high rates, of 6.4 cm, are likely to reduce final emergence and growth.

3. EFFECTS OF RATES AND TIMING OF COMPOST APPLICATION ON GROWTH AND DEVELOPMENT OF CORN AND SOYBEANS ESTABLISHED UNDER ZERO TILLAGE MANAGEMENT

3.1 Objectives

The objectives of this study were to determine the limitations or benefits of increasing rates of application of compost on the growth and development of zero-till planted corn and soybeans when applied in the late fall or in the spring.

In particular, an attempt was made to answer the following through the field trials:

Ë the effect of various rates of compost, left unincorporated into the soil, on corn and soybean development, nitrogen response and economic yield;

Ë the effect of a fall versus spring application of compost on the soil nitrate levels at planting; and,

Ë the degree of transport by surface runoff water of fall applied compost.

3.2 Study Methods

3.2.1 Experimental Design

Two separate trials were designed: one for corn and one for soybeans. The research plots were established on a well drained Guelph loam soil in a field which was previously in soybeans. The site was a field adjacent to that in the main trial described in Section 5. The corn plots measured 20 m long and 4.5 m wide (one planter width). The soybean plots measured 15m long and 4.6m wide (a drill width).

Compost application rates of approximately 0, 100, 150 and 300 Mg ha^{-1} (wet weight) were applied using a Bannerman "Turf-Topper" topdressing machine to obtain uniform coverage of the plots. Three passes of the machine were necessary to cover the total width of the plot. The average, as-applied, application rates achieved were used to describe the treatments in the report (Appendix B.1).

The experimental design of each trial was a randomized complete block design (RCBD) of four blocks (reps) of four rates of compost either applied in the fall or in the spring.

The compost source used in the trials was a clean, finished, and screened material from Scott's Composting Farm. The material was delivered to the site in November, 1994, for use in both fall and spring applications. Fall applications were made on November 3 - 7, 1994. Spring applications were made on May 11 - 12, 1995. A sample of compost was collected during each pass of the topdressing machine, weighed, and a composite sample retained for each plot. A subsample was dried at 60EC and weighed for determination of moisture content. Six samples for each of the spring and fall applications were submitted for analysis of total metals, nutrients and soluble salts (Appendix B).

The compost materials were not incorporated into the soil with the exception of the soil disturbance which occurred during zero-till planting. Corn (Pioneer 3921) was zero-till planted in 75 cm rows using a John Deere Maximerge planter, modified for zero-till planting, on May 20, 1995. Soybeans (OAC Eclipse) were seeded in 38 cm rows using a Tye no-till drill on May 26, 1995.

3.2.2 Fertilizer Applications and Response Trials

Potash fertilizer application rates were based on the soil test recommendations from a single composite soil sample obtained in the control plots within each trial. Application rates of 80 kg K_2O ha^{-1} for corn and 60 kg K_2O ha^{-1} for soybeans were made using a Val-Mar fertilizer spreader in May, 1995.

The nitrogen application for the corn was based on a nitrate-nitrogen soil test obtained from soil samples taken to 60 cm from each of the eight control plots on May 17, 1995. The application rate of 105 kg N ha^{-1} as NH_4NO_3, was the maximum rate recommended from these analyses. Nitrogen fertilizer was applied using a Val-Mar spreader to two thirds of the plot length on May 26. The remainder of the plot received no nitrogen fertilizer.

No nitrogen fertilizer was applied to the soybeans.

A nitrogen response trial for corn was set up in an area adjacent to the main trials. Six rates of nitrogen, 0, 75, 100, 125, 150, and 225 kg N ha^{-1}, were applied to 4 blocks of six plots in a randomized complete block design. The plots measured 4.5 m wide by 9 m long.

3.2.3 Runoff Losses of Compost

To provide an indication of the extent to which fall applied compost is transported by runoff during the winter and early spring, runoff collection flumes and collection containers were installed in four of the plots receiving the highest compost rate. The flumes were orientated in the direction of the slope gradient. Plots measuring 1 m x 4.5 m were delineated by wooden frames to define a runoff area. Runoff materials collected in the spring from the containers were dried and weighed. Samples were size separated into samples <2mm and >2 mm using a standard screen and loss on ignition was determined on each size fraction. The slope of the plots ranged from 4-6%.

3.2.4 Soil Sampling

Soil samples were obtained in the upper 60 cm of the soil profile in each plot in the corn trial on May 17, 1995, five days after the spring compost applications. Each sample was a composite of two single 0-60 cm soil cores. These samples were analyzed for nitrate-nitrogen.

3.2.5 Crop Sampling - Corn

Following planting, the number of plants emerged was periodically measured in two rows x 10 m. At the fourth leaf stage, the number of plants was recorded and the height of corn to the tip of the last fully developed leaf was measured for 10 plants. At silking, the number of plants with silks was recorded in 2 rows of 10 m.

Leaf tissue samples were obtained at silking from the mid third of the ear leaf of 20 plants within the plot. The tissue samples were dried, ground, and analyzed for total nitrogen.

Grain yields were obtained from 2 rows x 10 m in the area receiving nitrogen, and from 2 rows x 5 m from the area of the plot not receiving nitrogen. All plants were counted, the ears removed, weighed, and a 10-ear subsample retained for moisture content and shelling weight determination. Corn in the nitrogen response trials were similarly sampled from 2 rows x 7 m within each plot.

3.2.6 Crop Sampling - Soybeans

Following planting, the number of plants emerged was periodically measured in two rows x 10 m. The plant height to the growing tip of the main branch at 4 weeks after planting was measured for 10 plants, and time to first flower was recorded.

Leaf tissue samples were obtained from the top fully developed leaf at first flowering of 20 soybean plants. The tissue samples were dried, ground, and analyzed for total nitrogen.

Soybean yields were obtained from 2 rows x 10 m. Plants were cut at ground level, bagged, dried, threshed, and the grain weighed.

3.3 Study Findings - Corn

3.3.1 Soil Nitrogen

Nitrate levels in the 0-60 cm profile were not influenced by the timing of the compost application or the rate at which it was applied (Table 6). Nitrate-N levels averaged 74 kg ha^{-1} (±2.5) for all treatments.

Table **6.** **Nitrate-nitrogen soil test (kg N ha^{-1}) from May 17, 1995 sampling, corn trial**

Time of application	Rate of compost application (Mg ha^{-1})			
	0	95	148	288
Fall	74.1	63.2	70.6	77.5
Spring	73.3	66.8	87.1	77.0

ANOVA P: Time=.337; Rate=.199; Time x Rate=.554

3.3.2 Corn Emergence

At 12 days after planting (DAP) plots which did not receive compost produced the highest number of emerged plants while plots which received the highest rate of compost application resulted in the least number (Table 7).

Fall applications favoured higher plant emergence than spring applications over all rates. Fall applications resulted in 7.2 (±0.07) plants m^{-2} (pl m^{-2}) while spring applications resulted in 6.7 (±0.20) plants m^{-2} at 12 days after planting.

At twenty days after planting, there were no effects from compost application rates, nor from application timing. The overall plant population in the trial was 7.8 plants m^{-2} (±0.047). This value compares favourably with a final plant estimate at harvest of 77,000 plants ha^{-1}.

Table **7.** **Effect of compost rate and time of application on corn development and nutrient status**

Compost application rate, Mg ha^{-1}	**Emergence at 12 DAP, pl m^{-2}**			**Emergence at 20 DAP, pl m^{-2}**			**Percent of corn plants at fourth leaf on June 16**			**Height of corn plants at fourth leaf, cm**			**Silking, days after planting**			**Ear Leaf N Content, %**		
	Fall	**Spring**	**Mean**	**Fall**	**Spring**	**Mean**	**Fall**	**Spring**	**Mean**	**Fall**	**Spring**	**Mean**	**Fall**	**Spring**	**Mean**	**Fall**	**Spring**	**Mean**
0	7.4	7.4	7.4a	7.7	7.8	7.7	10.5	10.5	10.5	29.4	29.5	29.4	67	67	67	3.3	3.2	3.3
95	7.3	6.9	7.1ab	7.9	7.8	7.8	15.5	9.3	12.4	30.6	30.9	30.8	67	68	67	3.3	3.2	3.3
148	7.3	6.8	7.1ab	7.8	7.7	7.8	14.8	13.5	14.1	32.2	30.6	31.4	67	67	67	3.2	3.4	3.3
288	7.0	5.8	6.4b	7.9	7.5	7.7	33.3	14.8	24.0	31.0	28.6	29.8	66	68	67	3.3	3.2	3.2
Mean	7.2	6.7		7.8	7.7		18.5	12.0		30.8	29.9		67	67		3.3	3.3	
ANOVA P: Time		.008			.160			.004			<.001			.002			.661	
Rate		.005			.789			<.001			.013			.771			.971	
Time x Rate		.138			.383			.014			.021			.029			.619	

means followed by the same letter within a column are not significantly different at p#0.05, for main effects of rates.

3.3.3 Date of Fourth Leaf, Plant Height and Silking Date

Measurements made on June 16, 1995 indicated that the percentage of plants that had reached the fourth leaf increased with increasing compost application rate and averaged 33% higher with a fall application than a spring application (Table 7). The fall applications of compost produced a marked increase in the proportion of plants at fourth leaf at the highest rate of application. In contrast for spring applications compost rates had less effect on the percent of plants at the fourth leaf stage. By June 19, all corn plants had reached the fourth leaf stage.

At all rates, compost applied in the fall produced taller corn plants at the fourth leaf than without compost, while compost applied in the spring produced taller plants at fourth leaf except at the highest rate of application (Table 7). At the lowest rate of compost of 95 Mg ha^{-1} there was no difference between spring and fall timing of application on plant height. At higher rates of application plants were taller with fall applications.

Silking took place over the period of July 25 to 27, 66 to 68 days after planting (Table 7). Corn silked 1 day earlier at the high rate of compost applied in the fall, and 1 day later than the average under spring applied compost at the 95 and 288 kg ha^{-1} rates.

3.3.4 Ear Leaf Nitrogen Content

Yield loss due to nitrogen deficiency is expected in corn when ear leaf N content is at or below 2.5% (OMAF Publ. 296). Normal corn production may occur up to the maximum concentration of 3.5% N. Corn ear leaf nitrogen levels averaged 3.3% ±0.03 (Table 7). Compost application rates and timing had no effects on ear leaf nitrogen levels.

3.3.5 Corn Yields

Where N fertilizer was applied, fall applied compost produced 772 kg ha^{-1} higher corn yield than spring applied compost (Table 8). The time of application, however, interacted with the rate at which it was applied. Since increasing rates of spring applied compost tended to depress corn yields the primary effect of timing of the application was due to a positive influence of all rates of fall applied compost; particularly the highest rate which enhanced the yield by 984 kg ha^{-1} over the mean of the zero rate.

Table **8.** **Yield of corn receiving nitrogen fertilizer, kg ha^{-1}**

Time of application	Rate of compost application (Mg ha^{-1})				Mean
	0	95	148	288	
Fall	9475	9714	9874	10,312	9844
Spring	9182	9553	8797	8560	9072
Mean	9328	9633	9412	9561	

ANOVA P: Time <.001; Rate =.187; Time x Rate <.001

Differences in corn yield between fall and spring applications were evident only at the two highest rates of application where the corn did not receive nitrogen fertilizer (Table 9). The yield of corn was 30% higher at the highest rate of application when the compost was applied in fall versus the spring. In general spring applied compost again depressed yield with increasing rates whereas fall applications enhanced the yield.

Table **9.** **Yield of corn receiving no nitrogen fertilizer, kg ha^{-1}**

Time of application	Rate of compost application (Mg ha^{-1})				Mean
	0	95	148	288	
Fall	8431	8061	8986	9471	8737
Spring	8199	8059	8111	7341	7927
Mean	8315	8060	8549	8406	

ANOVA P: Time =.005; Rate =.601; Time x Rate =.036

Analysis of the difference in corn yield between N-fertilized and not fertilized revealed no effect of treatments suggesting the compost application time and rate effects were independent of N fertilization. The average increase in yield as a result of N fertilizer application was 1146 (±150) kg ha^{-1}.

A nitrogen response trial was used to assess the requirement of the site for N fertilizer. On the basis of the response equation derived from the data the expected corn grain yield was estimated at 7809 kg ha^{-1} with no nitrogen application. The maximum economic rate of nitrogen (MER-N) was calculated to be 146 kg N ha^{-1} based on a price ratio (PR) of 5. The yield predicted at the MER N is 9369 kg ha^{-1}. This yield is close to the yield level (9328 kg ha^{-1}) obtained on the control plots of the time and rate study, which had received 105 kg N ha^{-1}. The response curve predicted the yield levels within approximately 500 kg ha^{-1} of measured yields for control plots with or without nitrogen fertilizer (Table 10).

Table **10.** **Summary of corn grain yield and nitrogen response (kg ha^{-1})**

Rate of N applied to the trial based on N soil test in controls at a PR = 5	105
MER N (PR=5) from the response curve	146
Rate of N required for maximum yield from response curve	210
Expected grain yield from N response curve based on 105 kg N ha^{-1} applied	9102
Measured grain yield of control plots receiving N fertilizer	9328
Expected grain yield at zero nitrogen level from response curve	7809
Actual grain yield of control plots not receiving N fertilizer	8315

3.3.6 Summary

Stand Establishment
The final plant stand was not affected by compost treatments. However, the number of plants that emerged within two weeks after planting were fewer at the high rate of compost application and where the compost was applied in the spring, suggesting that spring applied compost may have some initial effects on seedling emergence.

Development
Plant development appeared to be accelerated by the highest fall compost application since a higher proportion of plants were at the fourth leaf and the plants were taller on June 16 and reached silking one to two days earlier than other rates at any timing of application.

Nitrogen Nutrition
There was no direct evidence that compost applications depressed nitrogen availability when N was applied at a rate based on the nitrate-nitrogen soil test values. Furthermore, there was no indication that the fall application of compost had altered the nitrate content of the soil. Ear leaf tissue samples indicated nitrogen nutrition was not limiting yield. Differences in yield between N-fertilized and not fertilized were similar for all compost treatments, implying a consistent effect of N fertilization on all treatments.

Corn Yield
There was no clear benefit or detriment of spring applied compost to grain yields, with or without N fertilizer applications. On the other hand, fall applications of compost produced higher yields at the high rate of application in the presence or absence of nitrogen fertilizer.

3.4 Study Findings - Soybeans

3.4.1 Soybean Emergence

Fourteen days after planting soybean emergence on the plots with no compost was very poor (Table 11). Within five days following soybean planting, a total of 37 mm of rain fell, causing the crusting of the soil surface. As a result emerging beans broke off at the soil surface. The presence of the compost at the lower two rates improved the emergence considerably over that achieved in the control. The highest rate of compost application resulted in the highest total number of plants emerged, presumably due to reducing the effects of rainfall energy on the soil surface. The effects were still evident in emergence measured at 19 days after planting.

Fall compost applications favoured higher plant emergence than spring applications at all rates. The effect was evident at 14 and 19 days after planting with the magnitude of the difference, 2.9 plants m^{-2}, remaining the same on both dates. Expressed as a percent of final emergence of the soybeans on average, 90.9% (±1.5) of the final stand was established by 14 days after planting for all treatments.

It is possible that soybeans drilled into the compost were planted at a shallower soil depth which in turn increased emergence in the high rate of compost. Observations confirmed that the seeds were planted into the soil and not the compost layer, however, the depth of planting achieved was not recorded.

Table **11.** **Effect of compost rate and time of application on soybean development and nutrient status**

Compost application rate, Mg ha^{-1}	Emergence at 14 DAP, pl m^{-2}			Emergence at 19 DAP, pl m^{-2}			Height of soybean plants at four weeks, cm			Percent plants at flowering on July 10			Leaf N Content at flowering, %		
	Fall	**Spring**	**Mean**	**Fall**	**Spring**	**Mean**	**Fall**	**Spring**	**Mean**	**Fall**	**Spring**	**Mean**	**Fall**	**Spring**	**Mean**
0	9.9	11.1	10.5c	10.8	12.0	11.4c	7.3	7.6	7.5b	54	56	55b	4.5	4.5	4.5b
93	18.8	15.0	16.9b	20.3	16.8	18.6b	9.0	8.1	8.6ab	69	57	63b	4.6	4.6	4.6ab
152	18.4	13.7	16.1b	21.2	15.6	18.4b	9.1	6.9	8.0ab	58	53	55b	4.5	4.7	4.6ab
300	26.0	21.7	23.9a	28.4	24.6	26.5a	9.8	9.0	9.4a	78	74	76a	4.9	4.7	4.8a
Mean	18.3	15.4		20.2	17.3		8.8	7.9		65	60		4.6	4.6	
ANOVA P Time	.011			.008			<.001			.218			.768		
Rate	<.001			<.001			<.001			.002			.036		
Time x Rate	.201			.138			<.001			.630			.376		

means followed by the same letter within a column are not significantly different at p#0.05, for main effects of rate.

3.4.2 Early Season Observations

As a result of the differences observed in the emergence and growth of the soybeans, additional measurements were made to permit a comparison of bare soil with the highest rate of compost. On June 14, 1995 soil water content was measured. Volumetric water content for the upper 0-15 cm of the soil was determined using TDR. Compost was removed from the area where the TDR rod was inserted so that the measurements reflected moisture in the soil profile. The data showed significantly higher water contents under the high rate of compost (0.332 cm^3 cm^{-3} ±0.013) than in the bare soil (0.268 cm^3 cm^{-3} ±0.010), regardless of whether the material was applied in the fall or spring.

On June 15 the number and type of weeds in the bare and high rate of compost plots were recorded (Appendix B.5). The frequency or number of plots in which a weed species occurred was generally higher in the bare soil than in the compost plots, with the exception of field bindweed. The number of weeds, particularly annual broad leaf and perennial weeds was higher in bare plots (average 51 pl m^{-2}) than in compost plots (8 pl m^{-2}). Several weed species appeared on the bare soil plots but not in those with compost such as, common yellow wood sorrel, lamb's-quarters, stinkweed, dandelion, mouse-eared chickweed, and Canada thistle. Dominant weed species noted at harvest in all plots to varying degrees were field bindweed, witchgrass, ragweed, and pigweed.

The higher weed pressures in the bare soil may have been due to: (i) low soybean stand density in the bare soil; (ii) smothering of weeds particularly, by the highest rate of compost; and, (iii) late application of chemical weed control due to hot and dry weather in June. Chemical weed control was carried out around June 24.

3.4.3 Plant Height at Four Weeks

Early growth of the soybeans was evaluated by measuring individual plant heights at four weeks after planting (Table 11). Plant heights increased with increasing compost rates of application made in the fall. Compost applications made at the highest rate in the spring produced plants similar in height to those produced under all fall applied materials.

3.4.4 Percent at Flowering on July 10, 1995

There were significant effects of the rate of application on the percentage of plants which had reached flowering on July 10 (Table 11). Plots receiving the highest rate of compost had a significantly greater percent of plants (76% ±3.1) in flower than any other treatments (58% ±3.5).

3.4.5 Leaf Nitrogen Content of Soybeans at Flowering

Yield loss due to nitrogen deficiency is expected in soybeans when the leaf N concentration at flowering is at or below 4.0% (OMAF Publ. 296). The maximum normal concentration is 6.0% N. While the timing of compost application did not influence leaf N concentration, increasing the rate of application from zero to 300 Mg ha^{-1} increased leaf N from 4.5% to 4.8% (Table 11).

3.4.6 Soybean Yield

Plant counts made 19 DAP had indicated significant treatment effects on the soybean stand (see Table 11) which was reflected in the final bean yield (Figure 6).

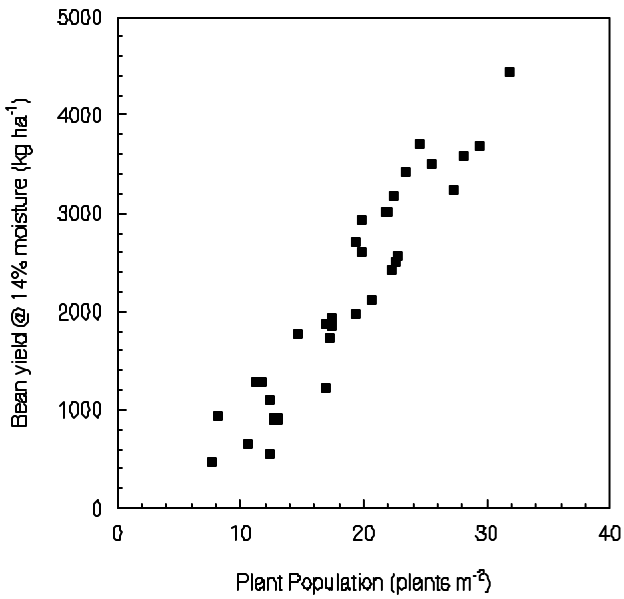

Figure 6. Relation of plant population and soybean yield.

Fall applications produced 380 kg ha^{-1} more beans than spring applications of compost (Table 12). The high rate of application produced the highest bean yield (3602 ± 139 kg ha^{-1}) while bare plots produced the lowest yield (902 ± 108 kg ha^{-1}).

Table **12.** **Soybean Yield (kg ha^{-1} @ 14% moisture)**

Time of application	Rate of compost application (Mg ha^{-1})				Mean
	0	**99**	**152**	**300**	
Fall	863	2185	2647	3861	2389
Spring	941	1836	1915	3343	2009
Mean	902	2011	2281	3602	

ANOVA P: Time =.016; Rate <.001; Time x Rate =.275

3.4.7 Summary

Stand Establishment

The soybean stand was significantly improved by compost application. The measurements suggested, however, a preference for fall applications over spring applications of compost.

Development and Growth
Compost appeared to accelerate development since beans grown on the bare soil and at the low rate of compost flowered, on average, later than soybeans under higher rates of compost. Early measurements of soybean growth, as indicated by plant heights at four weeks, suggested improved growth by soybeans which had received compost applications.

Soybean Yield
Soybean yields were higher as a result of compost applications. Fall applications favoured higher yields than spring applications. The improvement in yield as a result of compost applications is believed to be related to the increase in stand, the reduction in weed competition, and improved moisture relations. It may be suggested that the compost was not fully matured and time was needed to eliminate the negative effect on plant germination and growth. Increases in yield due to fall versus spring applications are consistent with results of the corn trial.

Nitrogen Nutrition
Soybean leaf nitrogen concentrations were generally adequate and there was no suggestion of interference of the compost application on the N nutrition in the soybeans.

3.5 Runoff Losses

The dry weights of compost applied at the highest application rate (fall-applied) averaged 155 Mg ha^{-1}, or 15.5 kg m^{-2}. The total weight of material removed over the winter period ranged from 40-194 g dry matter m^{-2}, and averaged 114 g m^{-2}; less than 1% of the amount of compost applied. However, only 35% of the runoff weight was accounted for by loss-on-ignition measurements. When corrected for the mineral material, the total runoff loss of organic material from the compost was 40 g m^{-2}, or 0.26% of the applied material.

4. APPLICATION OF COMPOST TO ALL GRASS HAY

4.1 Objective

Application of compost to row crops limits the window of application to preplant and post harvest periods. Both windows are restricted to relatively short periods during which excessively wet soil conditions may occur. Application to hay land opens up a third window, that between hay harvests, and extends the time applications may be made into the fall since the last hay harvest is made prior to September 1. In addition these extended periods are generally when the soil conditions are drier, resulting in less compaction from the applicator equipment.

Furthermore, the grass crop is one of the most sensitive species to nitrogen supply. A negative response to compost by a grass hay crop would be a clear indicator of induced nitrogen deficiency by compost application.

The objective of the experiment was to measure the yield responses of grass hay to a single spring application of compost, with and without a single application of supplemental nitrogen fertilizer.

4.2 Experimental Design

Four replications of a randomized compete block design using a 2 X 2 factorial arrangement of zero and 150 kg N ha^{-1} of fertilizer nitrogen and zero and 170 Mg ha^{-1} (as applied) of compost were applied to 1.5 meter by 10 meter plots of a long term, grass hay stand.

The nitrogen was hand broadcast on the respective plots as ammonium nitrate on May 11, 1995. Compost was spread on May 11 using the Bannerman topdressing applicator.

Two hay harvests were removed; the first on June 20 and the second on August 23, 1995.

Hay yields were estimated by cutting a swath the length of each plot using a sickle bar mower with a 85 cm cutting bar. The grass collected from each plot was weighed. A sub-sample was removed and dried at 80EC for 48 hours for moisture corrections.

4.3 Results

4.3.1 Species Composition

The hay stand was primarily orchard grass and timothy with lesser amounts of fescue and bluegrass. Application of the layer of compost tended to suppress and smother the development of the fescues and bluegrass, but not the orchard grass and timothy which exhibited greater ability to force their way through the compost layer. At the second harvest the suppression of the fescue and bluegrass had disappeared.

4.3.2 Yield Response

Nitrogen fertilizer had a significant positive impact on the dry matter yield of the first hay harvest (Figure 7). Compost alone, however, had no effect on hay production. Nitrogen increased overall dry matter yield by 78%.

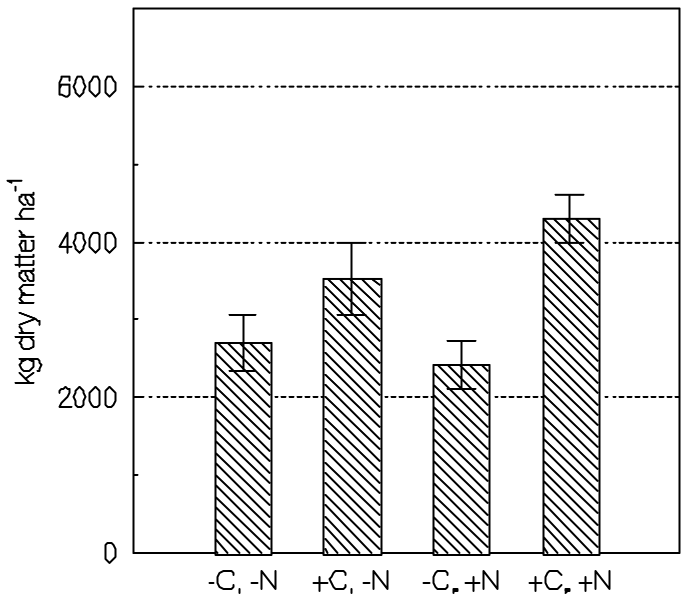

Figure 7. Effects of compost and nitrogen on dry matter production of grass hay harvested in August 1995 (standard error bars shown). ANOVA P: Compost<.001; Nitrogen=.326; C x N=.056. +/- denotes with/without.

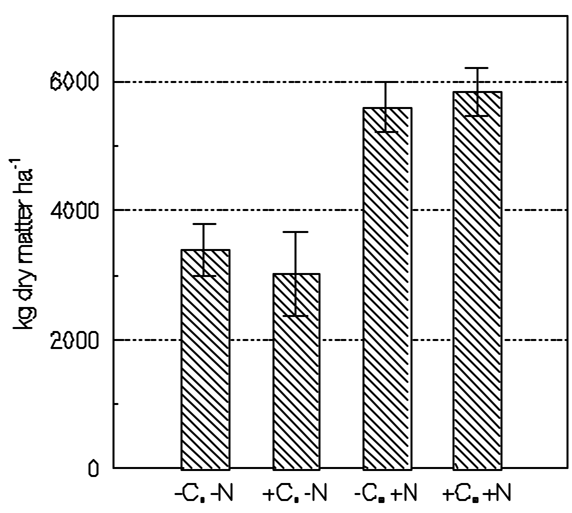

Figure 8. Effects of compost and nitrogen on dry matter production of grass hay harvested in June 1995 (standard error bars shown). ANOVA P: Compost=.810; Nitrogen<.001; C x N=.239. +/- denotes with/without.

At the second harvest nitrogen alone failed to increase hay yields (Figure 8). On the other hand, compost increased hay yields by 836 kg ha^{-1} where nitrogen had not been applied and by 1882 kg ha^{-1} where nitrogen was applied. Overall, compost increased the dry matter harvested at the second cut by 53%, regardless of N applications.

When the hay production was summarized for the season, effects of compost and nitrogen were evident (Figure 9). The total seasonal gain in dry matter production due to nitrogen, with or without compost, was 2764 kg ha^{-1}. The gain in dry matter attributable to compost, with or without nitrogen additions, was 1299 kg ha^{-1}.

The total seasonal gain in dry matter production due to compost in the presence of N fertilizer was 2100 kg ha^{-1}. Without the application of compost, nitrogen fertilization enhanced production by 32%, while the addition of compost increased the nitrogen response to 55%.

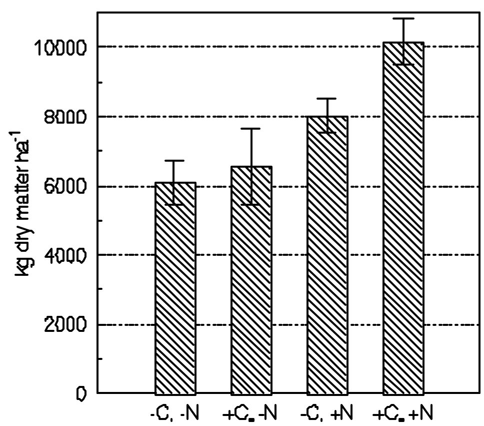

Figure 9. Effects of compost and nitrogen on total seasonal dry matter production (standard error bars shown). ANOVA P: Compost=.011; Nitrogen<.001; C x N=.071. +/- denotes with/without.

4.4 Discussion

No evidence of a reduction in hay production from an all grass stand due to compost application was evident where nitrogen was applied at a rate necessary to produce a satisfactory yield. In fact, greater response to the applied nitrogen was measured where the compost application was made. The improved nitrogen response may be attributed to an alteration of soil moisture conditions during the summer growth period, whereas a deficiency of water may have masked the potential nitrogen response where compost was not applied. Alternatively, nitrogen from compost may have been made available for the second cut. However, the slightly greater response of the hay which had previously received N suggests that nitrogen mineralized from the compost alone could not account for the increase in dry matter harvested at the second cut.

The data support the use of compost on hay land where the predominant species is a grass which must be adequately fertilized with nitrogen to realize the production potential of the grass.

Additional studies regarding the selection of species of grass for their ability to grow through a compost application, splitting the yearly nitrogen application, and splitting the yearly compost application to avoid some of the smothering effect are worthy of further consideration. In addition the potential for alfalfa to respond to the compost application is also worthy of investigation.

5. MAIN TRIAL - EFFECTS OF COMPOST SOURCES AND MANAGEMENT ON SOILS AND CROPS

5.1 Objectives

The application of composted organic waste to agricultural lands has the potential to benefit agriculture in terms of improving soil quality, but information on the environmental and agronomic aspects of the use of compost is needed to allow farmers to assess the risks and benefits of its use. The purpose of this study is to evaluate the impact of composted organic waste applications to farmland on soil quality, crop growth and yield, and water quality, in addition to assessing the economics of its application. The objectives are:

- to determine how compost type and the degree of incorporation into the soil influence the soil water content conditions early in the season, following its application;
- to examine the migration of decomposition products in the soil profile which could potentially reach groundwater supplies;
- to determine the implications of compost applications on runoff potential and water quality;
- to determine the effects of compost application on plant emergence, growth, and final yield;
- to evaluate the influence of the compost additions on soil biology using microbial biomass as an indicator; and
- to evaluate the intermediate term (3 years) effects on soil physical properties such as water holding capacity, and aggregate stability.

5.2 Study and Site Description

Trials were established on two farms located in Halton and Hamilton-Wentworth Regions near Campbellville, Ontario (Appendix C.1).

One site was located on Lot 1, Conc. XII, East Flamborough Twp., R.M. Hamilton-Wentworth. This property is operated by P. Lambrick. The soils on which the trial was established are well to moderately well drained Guelph loam and silt loam and imperfectly drained London silt loam developed on drumlins and other rolling landforms (Presant *et al.*, 1965). These soils were developed on calcareous loam and sandy loam parent materials. A horizon depths measured at four locations at the site ranged from 23 to 40 cm and depth to carbonates from 23-80 cm. The site is characterized by very gentle simple slopes (2-5%). In this report this site is referred to as the loam site.

The other site was located on the farm at Lot 7 and 8, Conc. IV, City of Burlington (New Survey) (formerly Nelson Twp.), Halton Region. The property is farmed by R. Sovereign. The soils on which the trial was established are largely imperfectly drained Chinguacousy loams, silt loams, and clay loams, with some poorly drained Jeddo clay loam developed in calcareous clay loam and silty clay loam glacial till deposits (Gillespie *et al.*, 1971). A horizon depths measured at 7 locations ranged from 20-40 cm and depth to carbonates ranged from 0 at the two lower slope sampling locations to 35-80 cm at the remaining sampling locations of the site. The site is characterized by nearly level to gentle complex slopes. In this report this site is referred to as the clay loam site.

The sites were chosen to reflect different soil types and to be managed within conservation farming practices. Baseline soils data were collected for each site (Appendix C.2, C.3).

The experiment was a randomized complete block design, with three blocks. The treatments involved a comparison of two food and yard waste compost sources obtained from Scott's Composting Farm (Sc) and LoamCrafters (Lc) composting facilities. The compost was either incorporated or left on the soil surface which was achieved by varying the timing of the last tillage operation, before and after the compost application. A control treatment received no compost. Compost applications were made annually beginning in 1994 and in successive years of 1995 and 1996, with new plots established each year in order to provide comparisons for effects of cumulative applications of compost in addition to single applications. Within each trial plots received the same inputs of fertilizer and herbicides.

A compost application rate of 100 Mg ha^{-1}, as applied, was used in the study. The compost had approximately 50% moisture content, and therefore the application rate approximated 50 Mg (dry) ha^{-1}. Actual rates that were achieved appear in Appendix C.5.

At the loam site, the trial was planted in a corn-corn-corn sequence following soybeans. At the clay loam site, the trial was planted in a corn-corn-soybean sequence following winter wheat. In 1996 it was decided to change the clay loam site from corn production to soybean production for the following reasons: (i) high variability in corn yield due to variable depth to a compacted horizon; a recording penetrometer measurements indicated a compacted zone exceeding 2000 kPa occurred at depths of 35-45 cm in several plots; (ii) shallower rooted soybeans would be less affected by the compacted zone; (iii) soil parameters being measured would not be influenced by the crop species. The agronomic practices used in the trials from 1993-1996 are tabulated in Appendix C.4. Incorporation of the compost was achieved through a cultivation or disking operation and planting was with no-till equipment. The farmer cooperators were responsible for field operations including tillage, planting, fertilizer applications and weed control. However, in 1995 and 1996, application of fertilizer was not carried out by the cooperators so that the plots could be split into areas with and without nitrogen fertilizer in order to provide a calculation of the delta yield of the treatments. Only grain yield was collected in the area without nitrogen fertilizer. The main trial where measurements were taken received nitrogen fertilizer.

Fertilizer application rates were determined by soil test results. In 1994, nitrogen was applied by the cooperators and was based on their normal management. In subsequent years, the nitrogen rate was determined by considering the nitrogen soil test, the 1994 rate of application, and the results of the nitrogen response trial.

Evaluation included the effect of the composts and their management on seasonal soil water content, corn emergence and stand, and final yield. Soil samples and soil solution samples were used to examine the migration of carbon, nitrogen and any metals which may be of concern, in the soil profile. Soil microbial biomass measurements were used to indicate changes in the soil environment as a result of compost applications. In the final year of the study, soil infiltration measurements were used to evaluate the potential for runoff from the plots, and soil samples were used to evaluate the changes in soil properties including water holding capacity and aggregate stability as a result of 1, 2 and 3 years of compost application.

5.3 Data Collection

5.3.1 Corn

The number of plants emerged in 2 rows by 10 m were counted at approximately 2 and 3 weeks after planting. Later, corn plants with silks emerged were counted in order to determine the silking date. The silking date is considered to be when at least 50% of the plants have silked. In 1995 and 1996, ear leaf tissue samples were taken at silking and analyzed for total nitrogen.

At harvest all cobs from each of 2 subplots measuring 2 rows by 7 m (1994) or 2 rows x 5 m (1995, 1996) were picked and weighed. The number of plants in the sample rows was recorded. A 10-cob subsample was weighed, and then dried, weighed, shelled and the grain weighed for moisture and shelling percentage determination. Yields were adjusted to 15.5% moisture.

In 1995 and 1996 harvest was made from a 2 row x 5 m section in the plots where no nitrogen had been applied.

5.3.2 Soybeans

Number of plants emerged in 2 rows of 8 m were counted at approximately 2 and 3 weeks after planting. Near flowering, soybean roots and nodules were sampled by digging six plants to 20 cm. The roots were washed and the nodules were air dried and separated for weighing.

At harvest, soybean plants from 2 rows of 8 m were cut, dried and threshed. Seed dry weights were determined. Yields were adjusted to 14% moisture.

Grain was analyzed for total nitrogen content.

5.3.3 Soil Water Content

Time domain reflectometry (TDR) rods and wires were installed to 20 and 80 cm between rows in each plot after planting. Soil water content readings were obtained periodically during June and July, and August. Values of soil water using TDR measured in the upper soil layer (0-20 cm) were separated into drying periods, periods during which no rainfall was recorded. A drying coefficient, k (d^{-1}), was obtained according to the method of Zhai *et al.* (1990) and the values of the coefficients compared for treatment effects. Lower drying coefficient values indicated slower evapotranspiration.

5.3.4 Microbial Biomass Carbon

Samples were collected near corn planting/emergence, near corn silking and near harvest (1994 only). Five soil samples were collected in the row and between the row in corn, between the row only in soybeans, and composited. Samples were obtained using a 1¼ inch diameter soil probe to a 15 cm depth. Total sample weight was measured and the samples analyzed for moisture content and soil microbial biomass carbon by the Analytical Services Laboratory, University of Guelph, using an extraction efficiency factor of 25% in the calculations (Voroney *et al.*, 1993).

5.3.5 Climate

A Class 'A' evaporation pan and a rain gauge were set up at each site and data were recorded periodically throughout the growing season. Measurement of pan evaporation provided an index of the combined effects of meterological conditions - solar radiation, air temperature, humidity and wind - on evaporation from lakes and potential evapotranspiration from land when water is not limiting (USDA, 1979).

5.3.6 Soil Solution; Leaching Potential

Soil solution samplers were installed at 30 and 80 cm in each plot in the fall after harvest. Solution was collected in the late fall or early spring when conditions were suitable. Samples were analyzed for NH_4, $N0_3$, dissolved organic carbon (DOC), ortho phosphorus and metals (As, Cd, Cr, Cu, Mn, Ni, Pb, Se, Zn) where sample numbers and quantities were adequate. Samples were obtained March 22, 1995 at 30 and 80 cm, April 18, 1996 at 30 and 80 cm, and November 21 (loam) or December 2 (clay loam), 1996 at 30 cm.

Potassium chloride (KCl) was applied to 4 m by 4 m plots adjacent to the research trials on each of three slope positions at each site in the late fall after harvest in 1994 and 1995. KCl was applied at a rate of 250 g $Cl^- m^{-2}$. Chloride analysis of soil cores to 1 m measured in 5 cm increments were used to characterize the leaching potential at the sites over winter. Soil cores were obtained in the spring for analysis (April 25, 1995 and May 2, 1996).

5.3.7 Nitrogen Response Trials

Four blocks of 6 plots measuring 4.5 meters by 8 m (1994) or 4.5 x 9 m (1995, 1996) were established adjacent to the main trials. Nitrogen, as ammonium nitrate, was broadcast by hand before corn planting at rates of 0, 75, 100, 125, 150, and 225 kg N ha^{-1}.

The maximum economic rate (MER) of N can be calculated from the yield curve produced in the nitrogen trials which is in the form: $Y=a_o + a_1 N + a_2N^2$, where Y is yield and N is the amount of fertilizer N applied: a_o, a_1 and a_2 are regression coefficients (Sheard *et al.*, 1990).

$$MER = \frac{PR - a_1}{2a_2}$$

where PR is the price ratio of cost of N: price of corn. A price ratio of 5 was used for purposes of analysis in this report.

5.3.8 Soil Characterization

At the end of the study, soil characterization was carried out on samples obtained from the control and from the incorporated compost treatments for each compost and year of application. Near the end of the cropping season in 1996, a pressure infiltrometer was used to characterize hydraulic properties of the soil at both sites.

Soil cores (3.2 cm dia.) were obtained from the surface to the A/B interface, the depth of A was recorded, and a composite of A-horizon samples weighed and analyzed for organic carbon (Tabatabai and Bremner, 1970). This sampling method allowed an assessment of carbon storage due to compost applications.

One soil sample (0-15 cm) per plot was obtained for determination of water stable aggregates (Pojasok and Kay, 1990), EC (Janzen, 1993), and soil fertility including Mn and Zn (Ontario Soil Management Committee).

Soil samples were obtained for depth increments of 0-20, and 20-40 in the control and for each compost type which had received three years of application. These samples were analyzed for total metals (Se, As, Cr, Co, Ni, Cu, Zn, Cd, Pb, Mo, Hg) (Marcille-Kerslake and Bolton, 1993; EPA Method 3051, 1994).

Measurements were made *insitu* with the Guelph Pressure Infiltrometer (GPI), and also by taking soil cores for laboratory measurements. The procedures used are similar to those used by Kachanoski *et al.* (1989) and O'Neill *et al.* (1990) for measuring the influence of tillage and cropping systems on soil hydraulic properties in the Agriculture Canada Soil Water Environmental Enhancement Program (SWEEP).

The Guelph Pressure Infiltrometer (GPI) is designed specifically to measure field saturated hydraulic conductivity, K_F ($m\ h^{-1}$), and matric flux potential, M ($m^2\ h^{-1}$) at the soil surface of insertion with minimal disturbance to the soil surface itself. The matric flux potential M is defined as the area under the hydraulic conductivity versus matric pressure head (h) relationship (Reynolds and Elrick, 1991).

The magnitude of M defines the strength of the capillary forces which pull surface applied water into the soil. Thus, K_F and M together define both the saturated and unsaturated components of water flow in soil.

The GPI measurements were made by driving the 9.6 cm diameter sealed steel ring of the infiltrometer 5 cm into the soil and applying a constant head of water, and measuring water flow out of the permeameter during subsequent infiltration. The near steady state values of water flow out of the infiltrometer, Q ($m^3\ h^{-1}$), were recorded for each of two applied heads (approximately 10 and 20 cm), which were also recorded. Estimates of K_F and M were obtained using the two-head technique and the equations outlined in Reynolds and Elrick (1991).

$$Q = (a\ H/G + Ba^2)\ K_F + (a/G)\ M$$

where *a* is the ring radius, H is the applied head, and *G* is a shape factor depending on the depth of insertion and the cross-sectional area of the surface ring. If the two-head analysis resulted in negative K_F or M values, then the one-head technique was used along with appropriate estimates of the ratio of K_F/M, which are reasonably predictable based on soil texture (Reynolds and Elrick, 1991).

An undisturbed core (5 cm diameter, 5 cm long) was removed from within an area adjacent to the sealed GPI ring at each location at the time the GPI measurements were carried out. The core was taken to the lab for measurement of saturated hydraulic conductivity, K_S and the soil water release curve, 2 (h). K_S was determined on each core using the constant head method. The soil-water release curve 2 (h) was determined on the saturated cores using a standard pressure plate apparatus. Cores were placed in a pressure chamber and equilibrated at h=10, 333, and 15000 *cm* pressure. Soil water content was determined gravimetrically at equilibrium pressure values. Bulk density was determined from a final oven drying of the undisturbed cores. Laboratory measurements were made by the Land Resource Science Analytical Lab at the University of Guelph.

Total porosity 2_s was calculated from the saturated weight and bulk density calculations. Different pore size categories were defined on the basis of their water holding properties. Macroporosity was defined as the volume of pores that would be filled at matric pressure head less than h=10 cm. This was calculated from the difference between 2_s and 2 (h=10 cm). The amount of drainable water porosity calculated as the difference in water content at h=10 cm and water content at matric pressure head h=333 cm. The amount of plant available water porosity is the difference between soil water content at h=333 cm and h=15000 cm. The water content at h=15000 cm, 2_R, is defined as residual water content porosity.

The field GPI and laboratory measurements of hydraulic properties were taken at the loam site between October 29 and November 5, and at the clay loam site between November 6 and 18, 1996. Three replicated GPI measurements and matching undisturbed cores were taken from plots with the Lc compost and the Sc compost, after 1 yr, 2 yrs, and 3 yrs of application. Three replicated measurements were also taken on an area with no compost (i.e. check treatment) at both sites.

The results of the two-head GPI analysis resulted in a large number of negative K_F or M values. Thus, the K_F values calculated from the one-head analysis are used for all reporting.

5.3.9 Data Analysis and Presentation

Data were analyzed using analysis of variance (ANOVA). Compost treatments, source and tillage were consistent during the period of the study while effects of years were introduced in 1995 and increased to three levels in 1996. In the ANOVA, the effect of the control is a contrast with the mean of all compost treatments. Dunnett's test was used to compare specific means with the control. Least significant difference or Tukey's was used for means separation of several means. Differences were tested at P#0.05. Probability levels for differences may be reported in report tables or text. Means may be presented in figures and text plus or minus the standard error of the mean.

Some data appear in Appendix C rather than in the main body of the report.

5.4 Results - Loam site

5.4.1 1994 Season

Corn growth and development

A uniform stand was obtained across the entire trial in 1994. At 15 and 23 DAP the plant populations were 6.2 and 6.6 plants m^{-2}, respectively, and were not influenced by treatments (Appendix C.9).

On average, corn silked 65 DAP where compost was applied, relative to the control, which silked on average at 68 DAP.

Corn yield

At the loam site in 1994, the compost treatments increased grain yields by 1051 kg ha^{-1} (Table 13) (Appendix C.11) over the control. There was no difference, however, between the sources of compost or of incorporating the compost materials.

Table **13.** **Grain corn yield (kg ha^{-1}) at loam site, 1994**

	Incorporated	Surface	Mean	Mean both composts
Sc compost	8266	7593	7930	7959
Lc compost	8145	7829	7987	
Control	6908			
ANOVA P:	Control=.023; Compost=.883; Tillage=.212; C x T=.646			

A yield of 8059 kg ha^{-1} was predicted by the nitrogen response curve (Appendix C.7.1) for the actual rate of nitrogen of 129 kg N ha^{-1} applied to all treatments and was only slightly greater than the 7959 kg ha^{-1} obtained where the corn received compost and fertilizer applications (Table 14). This analysis would suggest an insignificant yield depression of three percent or less due to the compost.

Table **14.** **Summary of corn grain yield and nitrogen response, loam site 1994 (kg ha^{-1})**

Rate of N applied to trial	129
Recommended N application rate based on soil N test (PR=5)	115
MER-N (PR=5) from N response curve	131
Expected grain yield from N response curve at actual rate N applied	8059
Measured grain yield of control plots receiving N fertilizer	6908

Soil water content

Soil water content measurements began one week after corn planting. Soil water content declined in the 0-20 and 0-80 cm depths during June but increased by June 30th due to 43.5 mm of rainfall which fell from June 24-30 (Figure 10). Subsequently, soil water content declined overall. From July onward, the soil water content levels were higher in the surface than in the total profile. Treatments had no significant effect on the soil water content in the upper soil depth, or on the rate of drying for the drying period June 15-22. Small differences in water content appeared between some treatments at the 0-80 cm depth but a pattern was not evident.

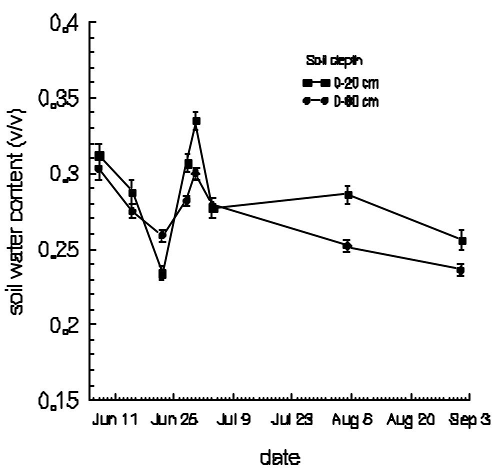

Figure 10. Mean soil water content at the loam site, 1994 (standard error bars shown).

Soil solution

Chloride sampling indicated that leaching of soluble materials from the soil profile had occurred over the winter. Soil solution collected at 30 cm contained lower concentrations of NO_3 under compost treatments than under the controls (P=0.023) although all averaged concentrations in excess of 10 ppm (Figure 11). Similarly, at 80 cm, concentrations of NO_3 were higher in solution from the control plots than from those with compost (P=.008). Average concentrations were at 10 ppm for Sc compost, but greater than 10 ppm on average for Lc compost and the control (Appendix C.13).

Orthophosphate was not detected in most samples. Dissolved organic carbon levels averaged 47 mg C L^{-1} and were not significantly different among treatments at 30 cm. At 80 cm there was insufficient data for DOC to interpret compost effects (Appendix C.15).

Soil microbial biomass carbon
At each sampling date, concentrations and mass of microbial biomass C measured in the 0-15 cm depth were not significantly affected by treatments (Appendix C.16). Amounts of biomass C averaged from 120 (±12) g C m^{-2} near silking to 140 (±18) g C m^{-2} after planting.

5.4.2 1995 Season

Corn growth and development
The plant stand was uniform when measured 13 DAP, when the population averaged 5.8 (±0.15) plants m^{-2} (pl m^{-2}). At 20 DAP, the average population ranged from 7.2 to 7.8 pl m^{-2}. A significant interaction of compost type and years of application was evident. Second year applications of the Sc material produced higher plant population (7.7 pl m^{-2}) than first year applications (7.2 pl m^{-2}), while the reverse trend was true with the Lc material, where the populations averaging 7.3 and 7.7 pl m^{-2} for second and first year applications, respectively (Appendix C.9).

Corn silked between 66 and 69 DAP on individual plots, suggesting a fairly uniform plant development across the trial. However, corn tended to silk one day earlier where compost was applied, on average 67 DAP, relative to the control, which silked on average 68 DAP (P=.077) (Appendix C.9).

Ear Leaf Nitrogen
Ear leaf nitrogen concentrations exceeded the critical minimum concentration of 2.5% for all treatments. There were no significant treatment effects on the level of N in the leaf tissue (Appendix C.9).

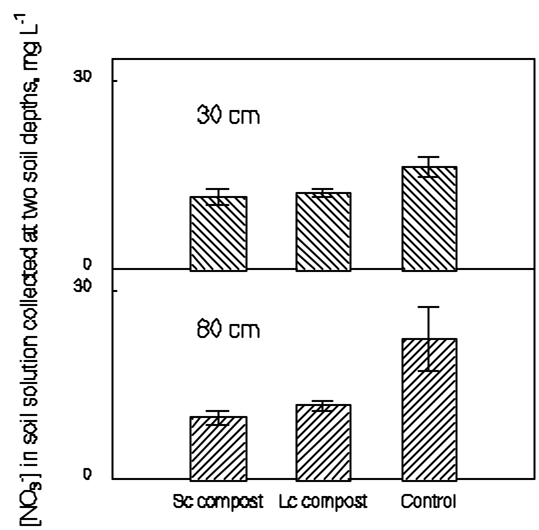

Figure 11. Nitrate levels in soil solution at the loam site (standard error bars shown).

Corn yield

Where corn received nitrogen fertilizer compost resulted in higher corn yields overall than no compost (Table 15) (Appendix C.11). The compost treatments averaged 9383 kg ha^{-1} while the control yielded 8659 kg ha^{-1}, an increase of 724 kg ha^{-1} in yield due to compost. Incorporation of the material had contrasting effects on yield between the two compost materials; surface applications of Lc compost resulted in the highest yield of 9806 kg ha^{-1}.

Table **15.** **Effects of compost grain corn yield (kg ha^{-1}) with N fertilizer at the loam site, 1995**

	Incorporated	Surface	Mean
Sc compost	9343	9086	9214
Lc compost	9297	9806	9552‡
Mean	9320	9446	
Control	8659		

ANOVA P: Control=.012; Compost=.074; Tillage=.498; Year=.657; C x T=.043; C x Y=.730; T x Y=.992; C x T x Y=.846

‡ indicates significantly different from control in column according to Dunnett's at p#0.05

In the absence of nitrogen fertilizer, at the loam site, the control produced a yield of 6884 ±198 kg ha^{-1} (Table 16). Corn receiving the Lc compost produced a higher grain yield (7948 ±192) than that receiving Sc (6783 ±165) without N fertilizer.

Table **16.** **Effects of compost on grain corn yields (kg ha^{-1}), without N and delta yield at the loam site, 1995**

	without N fertilizer		Delta Yield
Sc compost	6783	7366	2432
Lc compost	7948‡		1604
Control	6884		1776
ANOVA P:	Control=.210; Compost=.000; Tillage=.630; Year=.248; C x T=.704; C x Y=.805; T x C =.838; C x T x Y=.944		Control=.564; Compost=.008; Tillage=.986; Year=.450; C x T=.310; C x Y=.653; T x Y=.860; C x T x Y=.947

‡ indicates significantly different from control in column according to Dunnett's at p#0.05

The difference in yield between N-fertilized and not fertilized indicated a greater response of corn under Sc compost, to nitrogen fertilizer, compared with Lc.

Comparisons of corn yields between each compost source and the control showed that the Lc compost produced higher yields than the control with and without N fertilizer, while the Sc compost could not be considered significantly different. In fact, the Lc compost increased yields over the control by 893 kg ha^{-1} with N fertilizer, and by 1064 kg ha^{-1} in its absence. By this same analysis, the delta yields were not significantly different.

All treatments averaged higher corn yield, both with and without nitrogen, than was predicted by the nitrogen response curve (Table 17) (Appendix C.7.2). The control plots in the main trial exceeded expected yields by 534 and 756 kg ha^{-1} with and without N, respectively.

Table **17.** **Summary of corn grain yield and nitrogen response, loam site 1995 (kg ha^{-1})**

Rate of N applied to trial	131
Recommended N application rate based on soil N test (PR=5)	127
MER-N (PR=5) from N response curve	117
Expected grain yield from N response curve at actual rate N applied	7903
Measured grain yield of control plots receiving N fertilizer	8659
Expected grain yield at zero-N level from response curve	6350
Measured grain yield of control plots not receiving N fertilizer	6884

Soil water content

Soil water content in the upper soil layer (0-20 cm) was not significantly affected by treatments throughout the season. However, the rate of drying in this layer, measured for the period of June 9-20, tended to be higher for the control (.028 d^{-1}) than for the compost treatments (.020 d^{-1}) (P=0.051).

Over the 0-80 cm depth of soil differences in soil water content due to treatments were inconsistent and small in magnitude. The average soil water content at the site is shown in Figure 12.

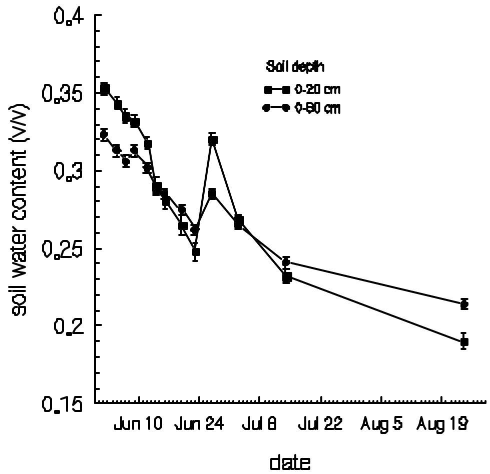

Figure 12. Mean soil water content at the loam site, 1995 (bars are standard error).

Soil solution

Chloride concentrations were similar throughout the soil profile, indicating that soluble materials in the profile were leached below 80 cm over the winter.

Average concentrations of ammonium and nitrate were not significantly affected by treatments, and were 0.49 mg NH_4-N L^{-1} and 7.5 mg NO_3-N L^{-1} (Appendix C.13). Concentrations of DOC were nearly twice as high in association with the control treatments, at 71 mg C L^{-1} (P=.007), than with either the Sc (24 mg L^{-1}) or the Lc (36 mg L^{-1}) composts (Appendix C.15).

Similarly, at the 80 cm sampling depth, solution concentrations of ammonium and nitrate averaged 0.58 mg NH_4-N L^{-1} and 6.7 mg NO_3-N L^{-1} and were not different among treatments. At 80 cm DOC averaged higher under the control (41 mg L^{-1}) than compost (22 mg L^{-1}).

Ortho phosphates were detected in few samples at either depth.

The metals Cu, Mn, Ni, and Zn were detected in a few solution samples (Table 18). Drinking water quality guidelines were exceeded in 1 sample of 5 for Mn; this was in association with a compost treatment and was detected in a sample obtained at 30 cm soil depth. At the 80 cm depth, 2 of 3 samples containing Mn exceeded guidelines for drinking water, but only 1 of these was in association with a compost treatment. It is important to note that the inorganic elements detected are not parameters related to health in drinking water; Cu, Mn, and Zn objectives are related to aesthetic quality.

Table **18.** **Metals detected in solution samples (mg L^{-1}) at the loam site, spring 1996.**

Metal	# samples detected	minimum amount detected	maximum amount detected	Ontario Drinking Water Objectives (mg L^{-1})	number of samples exceeding guideline
30 cm soil depth; total samples analyzed=33					
Cu	1	.14		#1	0
Mn	5	.01	.13	#.05	1
Zn	3	.13	.31	#5	0
80 cm soil depth; total samples analyzed=33					
Mn	3	.05	2.6	#.05	2
Ni	6	.07	.34	not established	
Zn	12	.09	.62	#5	0

‡ Source: OMOE, 1984

Soil microbial biomass carbon

Soil microbial biomass carbon concentrations and mass in the soil were not affected by treatments at either sampling date. Concentrations averaged 634 (±18) mg C kg $soil^{-1}$ in June near planting and 481 (±18) mg C kg^{-1} in August near silking. Mass of microbial C averaged 142 (±4.2) g C m^{-2} in June and 105 (±4.0) g C m^{-2} in August (Appendix C.16).

5.4.3 1996 Season

Corn growth and development

In 1996, compost treatments appeared to influence the emergence measured at 16 and 22 days after planting, though a pattern is not clear. The three way interaction was significant. In addition, interactions of compost with both tillage and year were statistically significant at both dates (Appendix C.9). At 22 days after planting the control averaged 6.4 plants m^{-2} while compost treatments averaged 5.7 to 7.3 pl m^{-2}.

The corn silked between 71 and 79 days after planting, which was August 13 to August 21. In the control, silking was at 76 DAP, the same on average as with the corn to which Sc compost was applied. Where the Lc compost was applied the corn silked earlier, at 74 DAP.

In addition, silking occurred earlier (at 74 DAP) where the materials were incorporated than where they were surface applied (at 76 DAP). It appeared that where there had been previous applications of compost, incorporation of the materials was preferable in 1996 and corn silked 3-4 days earlier (at 73 and 74 DAP) than surface applications (77 DAP). This was not the case for areas receiving their first application, in which case incorporation seemed to have no effect (75 DAP).

Ear Leaf Nitrogen

Ear leaf N averaged 2.0 - 2.7% N (Appendix C.11). Incorporation of the compost resulted in an overall significantly higher ear leaf N (2.5% ±0.07) than leaving the compost on the soil surface (2.3% ±0.06). The control averaged 2.6% (±0.33), with individual values of 2.0 - 3.1%.

Corn yield

Grain corn yields were low across the site which is a reflection of late seeding in a cold planting season, high rainfall, possible loss of N by leaching, the third consecutive year of corn, and late weed control (Appendix C.11).

The control yielded 3861 kg ha^{-1} (Table 19). Yields were higher where the compost material was incorporated rather than left on the soil surface; incorporation resulted in a 14% increase in yield compared with surface applications. The Lc compost increased yields by 521 kg ha^{-1} over the Sc compost. Neither corn yields due to compost sources or incorporated or surface application were different from the control.

The yield of incorporated treatments was less consistent with Sc compost than with Lc compost; with the Sc compost the first and second year applications had lower yields than third year applications.

Table **19.** **Effect of incorporation and compost source on corn yield with N fertilizer (kg ha^{-1}) at the loam site, 1996.**

	Incorporated	**Surface**	**Mean**
Sc compost	3887	3543	3730
Lc compost	4599	3903	4251
Mean	4243	3738	
Control	3861		

ANOVA P: Control=.603; Compost=.001; Tillage=.002; Year=.161; C x T=.168; C x Y=.124; T x Y=.215; C x T x Y=.038

In the absence of nitrogen fertilizer incorporation of compost into the soil resulted in higher grain corn yields than where it was left on the soil surface (Table 20). The increase in yield due to incorporation in the zero-N plots averaged 316 kg ha^{-1} and neither of the compost incorporated or surface applied treatments produced yields significantly different than the control. In the absence of N, the control treatment yielded 2231 kg ha^{-1}, and overall treatments averaged 2428 kg ha^{-1}.

Table 20. Effect of incorporation and compost source on corn yield without N fertilizer and delta yield (kg ha^{-1}) at the loam site, 1996.

	Without nitrogen		Delta Yield	
	Incorporated	**Surface**	**Incorporated**	**Surface**
Sc compost	2618	2108	1270	1446
Lc compost	2580	2438	2019	1465
Mean	2599	2283	1645	1456
Control	2231		1630	
ANOVA P:	Control=.422; Compost=.323; Tillage=.033; Year=.120; C x T=.215; C x Y=.857; T x Y=.058; C x T x Y=.608		Control=.805; Compost=.027; Tillage=.298; Year=.260; C x T=.017; C x Y=.252; T x Y=.293; C x T x Y=.038	

The increase in yield due to N fertilizer, the delta yield, tended to be most consistent among treatments receiving 3 years of compost. These delta yields were not significantly different from the control, and were in the order of 1600 kg ha^{-1} (Table 20).

The nitrogen response (Appendix C.7.3) produced a curve with a positive quadratic coefficient (a_2), suggesting that N was lost from the system such as by leaching (Appendix C8; see also Table 39, pg. 65). In addition, the response curve was low relative to those of previous years, reflecting the high early season rainfall and late weed control at the site in 1996. Due to the unconventional shape, the response curve may be of limited use for interpretive purposes (Table 21). Measured grain yields in the control of the main trial exceeded the yields predicted by the N response curve based on the actual N applied by 43% and where no nitrogen was applied by 18% (Table 21).

Table **21.** **Summary of corn grain yield and nitrogen response, loam site 1996 (kg ha^{-1})**

Rate of N applied to trial	131
Recommended N application rate based on soil N test (PR=5)	66
MER-N (PR=5) from N response curve	39
Expected grain yield from N response curve at actual rate N applied	2704
Measured grain yield of control plots receiving N fertilizer	3861
Expected grain yield at zero-N level from response curve	1892
Measured grain yield of control plots not receiving N fertilizer	2231

Soil water content

Compost treatments resulted in no measurable differences in soil water content in the upper (0-20 cm) soil depth. Over the period August 16-20, the coefficient for soil drying indicated slower rates of drying under the Sc surface applications and Lc incorporated applications. Over all treatments the drying coefficient averaged 0.029 d^{-1}.

Differences in water content over the 0-80 cm soil depth did not suggest meaningful effects of treatments on soil water content in the rooting zone.

Mean seasonal soil water content patterns are shown in Figure 13.

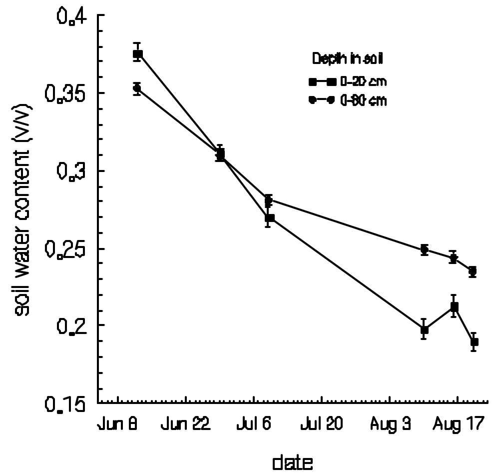

Figure 13. Mean soil water content at the loam site, 1996 (standard error bars shown).

Soil solution

Nitrate levels in the soil solution (30 cm) removed in December, 1996, were higher under incorporated compost treatments (10.1 mg L^{-1}) than surface applications (6.9 mg L^{-1}) although they were not different from levels in the control which averaged 8.0 mg L^{-1} (Appendix C.13). Ammonium and DOC levels did not differ significantly among treatments and averaged 0.25 mg N L^{-1} and 13.5 mg C L^{-1} (Appendix C.15), respectively.

Soil microbial biomass carbon

There were small differences in the concentration of microbial biomass C in the soil measured in June after planting due to incorporation of the compost material (Appendix C.16). Where the compost had been left on the soil surface, biomass C levels averaged 792 mg C kg $soil^{-1}$ (167 g C m^{-2}) while where it had been incorporated, levels averaged 627 mg C kg $soil^{-1}$ (133 g C m^{-2}). The control contained 530 mg C kg^{-1} (117 g C m^{-2}).

In the August sampling, there were no significant treatment effects on the concentration or mass of microbial C in the 0-15 cm soil layer. The site average was 381 (±46) mg C kg $soil^{-1}$ and 80 (±9.5) g microbial biomass C m^{-2}.

Soil characterization

<u>Metal content:</u>

Three years of compost addition did not result in higher levels of metals in the soil, measured at two soil depths of 0-20 and 20-40 cm, compared with the control treatments (Table 22). Concentrations of metals were below the upper limit of normal for soils as outlined by the MOEE in its compost guidelines.

Levels of metals were often found to be near the average for Ontario soils reported by Frank *et al.* (1976, 1979). Levels of Co and Zn in the soil were twice the average for Ontario soils and As levels in the soils were below average.

The concentrations of some metals, eg. Cr, Cu, Ni, Zn, including those in the control treatment where no compost was applied, were higher than in the original site baseline established in 1993.

Table **22.** **Total metal concentration (mg kg^{-1}) in soil resulting from 3 years of compost applications, loam site**

	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Zn	As	Se
0-20 cm soil depth											
Control	<1	9.7	22.3	29.3	.093	<2.5	22.0	18.0	95.7	2.9	<0.5
Sc compost	<1	10.1	20.7	33.0	.060	<2.5	21.7	18.0	100.7	1.2	<0.5
Lc compost	<1	8.0	17.0	30.0	.097	<2.5	17.7	18.0	90.0	1.9	<0.5
ANOVA P		.279	.322	.637	.406		.266	.420	.753	.339	
20-40 cm soil depth											
Control	<1	11.0	25.0	34.3	.053	<2.5	25.7	16.3	91.3	2.9	<0.5
Sc compost	<1	11.0	26.0	36.0	.080	<2.5	28.7	20.7	98.3	2.7	<0.5
Lc compost	<1	9.1	20.0	31.7	.073	<2.5	20.7	12.3	88.0	4.4	<0.5
ANOVA P		.562	.499	.608	.210		.406	.298	.676	.301	
MOEE guideline[1]	3.0	25	50	60	0.15	2.0	60	150	500	10	2
normal[2]	0.56	4.4	14.3	25.4	0.11	1.65	15.9	14.1	53.5	6.3	0.37 0

1. Source: Waste Reduction Office, Ontario Ministry of the Environment. 1991. Interim Guidelines for the Production and Use of Aerobic Compost in Ontario. Queen's Printer for Ontario. pp. 7-8.
2. Source Frank *et al.* (1976, 1979). Based on 296 farm fields sampled to 15 cm soil depth (1976). Based on 30 samples, 15 cm soil depth (1979). Data are the mean of all soils sampled and apply to the 0-20 cm depth only.

Soil fertility:

Soil test P levels were higher for soil with compost applications (23 mg/L) than without (12 mg/L) (Table 23). The Sc material resulted in slightly higher soil test P levels (25 mg/L) than the Lc compost material (20 mg/L). At these levels the recommended fertilizer application for corn would be identical at 20 kg P_2O_5 ha^{-1}.

Compost additions resulted in higher soil test K levels in the soil, with the Sc compost resulting in higher test levels than the Lc compost. Higher K-test levels were evident where the soil had received compost for 2 or 3 consecutive years.

Table **23.** **Soil test P and K levels (mg L^{-1}) in the soil and recommended fertilizer application for corn (kg ha^{-1}) in relation to compost additions, loam site**

Compost treatment	number of years of application	Soil test P	Recommendation P_2O_5	Soil test K	Recommendation K_2O
Sc compost	1	22	20	134	0
	2	24	20	140	0
	3	30	20	161	0
Lc compost	1	20	20	77	80
	2	20	20	113	30
	3	20	20	95	50
Control		12	50	64	80
ANOVA P: (for soil test)		Control=.002; Compost=.023; Year=.229; C x Y=.344		Control<.001; Compost<.001; Year=.045; C x Y=.123	

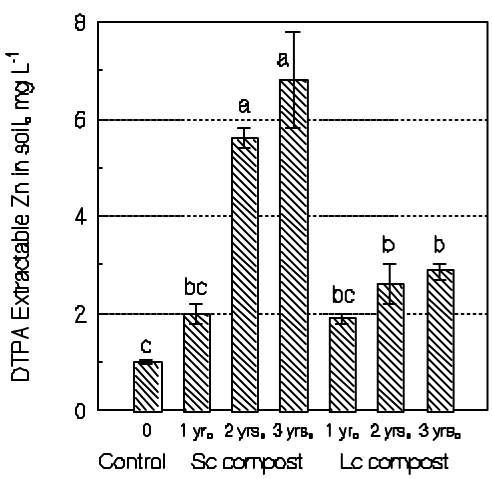

Figure 14. Effects of compost applications on level of DTPA extractable Zn measured in the soil at the loam site (standard error bars shown).

Increased amounts of DTPA extractable Zn in the soil was associated with compost additions (Figure 14). Two or three years of compost application, however, were required to increase the Zn levels in the soil. The increase was greater with the Sc than the Lc compost. Conversion of the treatment average DTPA Zn levels to the Zn index revealed values of 13 for the control and 17-39 for the composts. At <15, the control is likely to be Zn deficient for corn, suggesting both materials had removed the potential for Zn deficiency.

Soil test Mn levels were increased from 30 mg L^{-1} in the control to 35 mg L^{-1} under Lc compost, and 38 mg L^{-1} under Sc compost (Appendix C.18).

Soil pH averaged 7.5 under Lc compost applications and 7.3 for the control and Sc compost. Electrical conductivity was higher in soils receiving compost, but values for the control (0.12 mS/cm) and for the soil which received composts (0.16 mS/cm) were low and at a level suitable for most plants.

Soil carbon:

Compost applications increased the organic carbon concentration measured in the A horizon in the fall of 1996 (Figure 15) (Appendix C.18). Averaged over all years of applications, compost additions increased the organic carbon content of the A horizon by 0.36%. The total amount of carbon in the A horizon was also significantly higher with successive annual applications of compost (Figure 16). Annual additions of

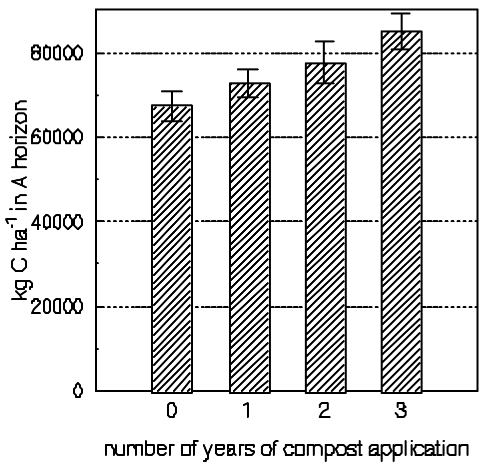

Figure 15. Organic carbon storage in A horizon at loam site (standard error bars shown).

compost, approximately 50,000 kg dry matter per year, resulted in approximately 5900 kg C ha^{-1} yr^{-1} increase in organic C in the A horizon.

Soil physical properties:
Water stable aggregates were not significantly different among treatments, and averaged 16% (±1.2) for the site.

A summary of the hydraulic parameters measured with the GPI and the undisturbed cores are given in Table 24 (see Appendix C.20).

The addition of compost resulted in a significant increase (P=0.014) in the total porosity (i.e. saturated soil water content) of the soil, and a corresponding decrease in bulk density. The addition of Sc compost resulted in a significantly higher (P=0.048) total soil porosity than the Lc compost (Table 24). The effect of compost on total soil porosity was to increase significantly as the number of years of compost application increased (Figure 17).

There was a significant interaction of compost type and years of application, on the effective soil pore size distribution. For the Sc compost, the first year of application resulted in changes to larger pores that hold water at less than 330 cm of pressure head (Figure 17, Figure 18, Table 25). However, after one year no changes in residual water content were measured. After years 2 and 3 of application, the Sc compost resulted in significant and increasing changes to the residual water content (Figure 19).

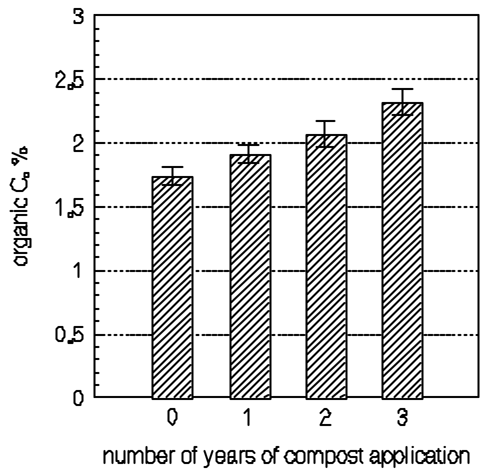

Figure 16. Concentration of organic C in A horizon at loam site (standard error bars shown).

In contrast to the Sc compost, the influence of application of the Lc compost was mainly in the larger pore sizes. The influence of the Lc compost after 3 years of application, on residual water content was minimal (Figure 19). Even for water held at a pressure head of 333, the influence of 3 years of Lc application was minimal compared to Sc compost (Table 24).

The difference in the influence of compost type on changes in specific pore-size categories is summarized in Table 25. Although the Sc compost (3 yrs.) increased the total porosity by .07 cm^3 cm^{-3}, the macropore and drainable water porosity decreased. The Lc compost (3 yr) increased total porosity by 0.054 cm^3 cm^{-3}, with almost all of the increase occurring in the macropore and drainable water porosity.

The K_S and K_F values tended to increase if compost was applied (Table 24). However, the results were quite variable for both measurements and the results are not statistically significant. For both compost types, the K_S and K_F values after 3 yrs of application were higher than the check plots.

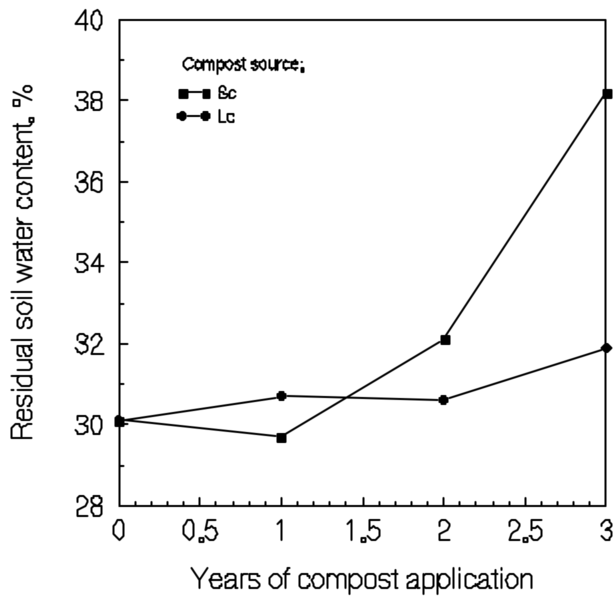

Figure 17. Effect of compost type and years of application on residual soil water content at the loam site.

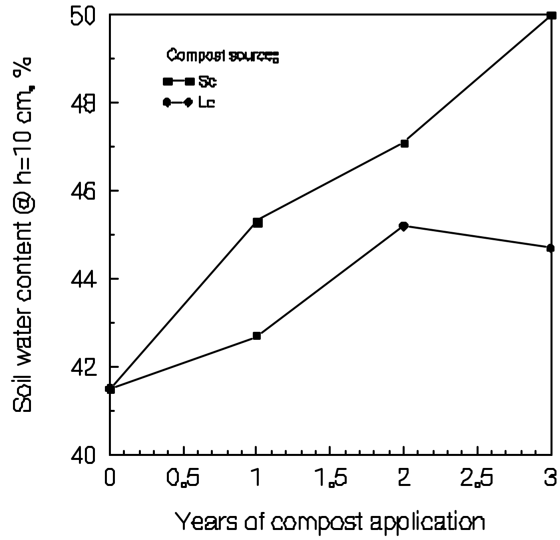

Figure 18. Effect of compost type and years of application on soil water content at a matric pressure head of 10 cm, at the loam site.

Table **24.** **Summary of surface hydraulic properties measured with the Guelph Pressure Infiltrometer and undisturbed cores for the loam site.**

Compost Application (yrs)	Bulk Density (g cm^{-3})	K_S** (cm hr^{-1})	K_F*** (cm hr^{-1})	Soil Water Content (cm^3 cm^{-3})			
				h*=0	h=10 cm	h=333 cm	h=15,000 cm
0 (control)	1.34	1.8	12.28	0.474	0.415	0.338	0.301
Sc compost							
1 yrs	1.23	4.0	19.48	0.528	0.453	0.360	0.297
2 yrs	1.28	45.7	16.06	0.520	0.471	0.390	0.321
3 yrs	1.22	41.1	14.94	0.548	0.500	0.433	0.382
Lc compost							
1 yrs	1.35	0.82	15.80	0.498	0.427	0.368	0.301
2 yrs	1.35	1.35	15.62	0.492	0.452	0.379	0.306
3 yrs	1.26	49.4	14.48	0.528	0.447	0.362	0.319

* h = soil matric pressure head
** K_S = saturated hydraulic conductivity
*** K_F = field saturated hydraulic conductivity

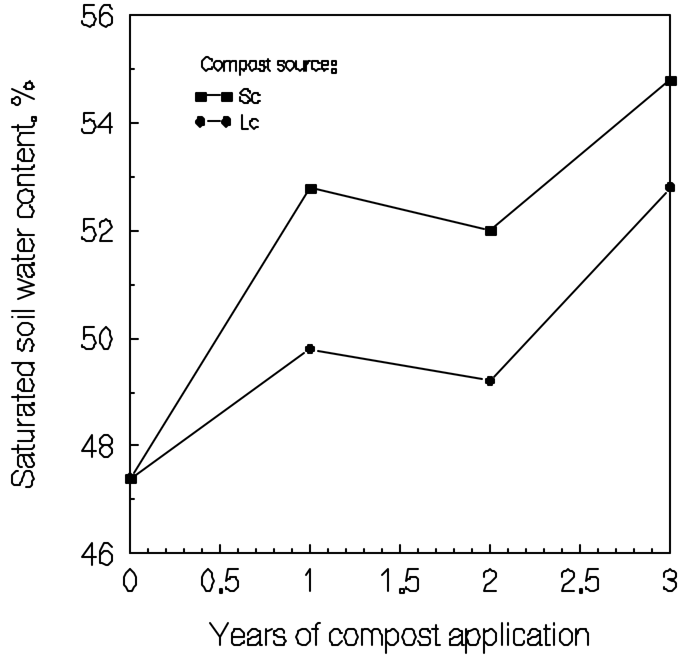

Figure 19. Comparison of the effect of compost type and years of application on saturated soil water content at the loam site.

Table **25. Influence of compost type (after 3 years of application) on soil pore size categories at the loam site.**

Pore Size Categories	**Soil Water Amounts (%)**		
	No compost	**Lc compost (3 yrs)**	**Sc compost (3 yrs)**
Residual	30.1	31.9	38.2
Plant Available	3.7	4.3	5.1
Drainable	7.7	8.5	6.7
Macropore	5.9	8.1	4.8
Total Porosity	**47.4**	**52.8**	**54.8**

5.5 Results - Clay loam site

5.5.1 1994 Season

Corn growth and development

Treatment effects were evident in the stand obtained at 16 and 23 DAP (Appendix C.10). Incorporating the compost reduced emergence by 1.1 pl m^{-2} below that obtained where the compost was not incorporated. By 23 DAP, emergence was also shown to differ between compost sources (P=.05). Average emergence with Sc compost was 5.5 pl m^{-2}, that with Lc was 6.1 pl m^{-2}, whereas the control was intermediate at 5.7 pl m^{-2}.

The corn silked at 70 DAP under compost applications in contrast to 66 DAP where no compost was applied.

Corn yield

Grain corn yields were lower overall with compost applications than without (Table 26) (Appendix C.12). The overall reduction in yield where compost was present was primarily due to lower yields with Sc compost, which produced yields 1647 kg ha^{-1} lower than with Lc compost.

Table **26.** **Effect of composts on grain corn yields (kg ha^{-1}) at clay loam site, 1994**

	Incorporated	**Surface**	**Mean**
Sc compost	5274	4521	4898‡
Lc compost	6058	7032	6545
Mean	5666	5777	
Control	7320		

ANOVA P: Control=.020; Compost=.008; Tillage=.849; C x T=.144
‡ value significantly different from control according to Dunnett's, at p#.05

The equation developed from the nitrogen response trial, predicted that at the rate of N applied of 115 kg N ha^{-1}, the yield of corn would be 8050 kg ha^{-1}, or 10% higher than measured in the field by the control which had received that rate of fertilizer N.

Yields of corn where compost was applied were 23% and 64% lower, for Lc and Sc compost, respectively, than the yield predicted by the N response curve at the fertilizer application rate of 115 kg N ha^{-1} (Table 27).

The response curve (Appendix C.7.4) also suggested that the maximum economic rate of N for this site of 155 kg N ha^{-1} was greater than the rate which was applied.

Table **27.** **Summary of corn grain yield and nitrogen response, clay loam site 1994 (kg ha^{-1})**

Rate of N applied to trial	115
Recommended N application rate based on soil N test (PR=5)	155
MER-N (PR=5) from N response curve	155
Expected grain yield from N response curve at actual rate N applied	8055
Measured grain yield of control plots receiving N fertilizer	7320

Soil water content

During June soil water content remained at high levels at depth and tended to be higher over the 80 cm depth than the water content over the upper 20 cm layer throughout the growing season (Figure 20).

Compost treatments had no significant effect on the soil water content measured in the surface (0-20), or total (0-80 cm) soil profile. Similarly, soil drying rates measured during a June 15-22 period in the upper soil depth were not significantly different among treatments and averaged .041 d^{-1}.

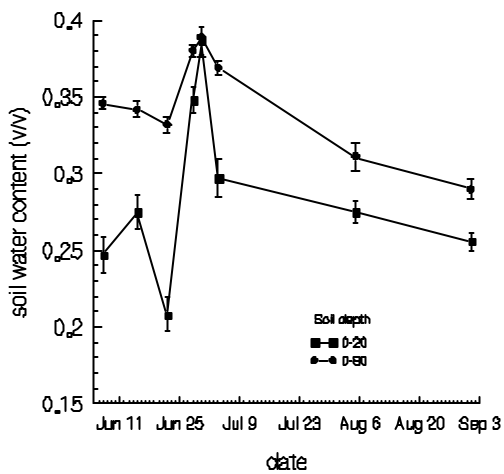

Figure 20. Mean soil water content at the clay loam site, 1994 (bars are standard error).

Soil solution

Chloride sampling indicated that some chloride remained in the soil profile above the 60 cm soil depth suggesting the profile was not completely leached of soluble material over winter.

Soil solution measured at 30 cm from the soil surface tended to have lower concentrations of NO_3 under Sc material (6.6 mg L^{-1}) than under the Lc compost (13.4 mg L^{-1}) (P=.055) but neither value was significantly different from the control (11.4 mg L^{-1}) (Figure 21) (Appendix C.14). Average nitrates in the control and compost treatments exceeded 10 ppm. Likewise, at 80 cm, solution from the plots receiving Sc compost had lower nitrate levels than those receiving Lc compost (P=.045). All treatments at 80 cm averaged <10 ppm.

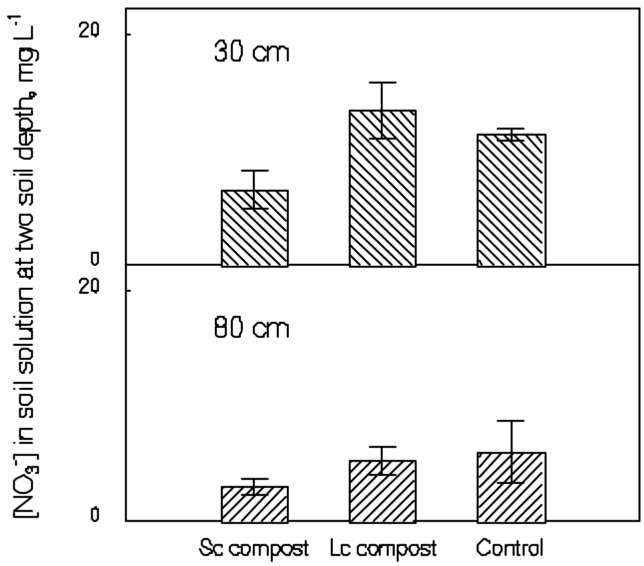

Figure 21. Nitrate levels in soil solution at the clay loam site (standard error bars shown).

Dissolved organic C levels were not significantly different among treatments with levels of 49 and 29 mg C L^{-1} at 30 and 80 cm, respectively (Appendix C.15).

Soil microbial biomass carbon

In October, there was a higher concentration (P=0.03) and mass (P=0.057) of microbial biomass C in compost treatments relative to the control, but no differences in these parameters were evident at two other sampling dates in June and August. The mass of biomass C was 141 (±7.5), 163 (±8.4), and 171 (±7.5) g C m^{-2} in the upper 15 cm of soil, when sampled near planting, silking, and after harvest, respectively (Appendix C.17).

5.5.2 1995 Season

Corn growth and development

At both 13 and 20 DAP, a 3-way interaction of compost source, incorporation and whether there had been one or two years of application (P=.053 at both dates) (Appendix C.10). In the second year of application there were no effects of incorporation of the materials on final stand and the two compost materials produced similar stands (average 7.3 pl m^{-2}). For first year applications, however, the compost type had divergent effects on the plant population, producing a relatively lower population under Sc where the material was incorporated (7.0 pl m^{-2}) and a relatively higher population under Lc where the compost was incorporated (7.8 pl m^{-2}), while surface applications of the composts showed no differences between the two materials (average 7.4 pl m^{-2}).

While the date of reaching silking on the control was not different overall from the compost treatments, there was a significant interaction of compost, tillage and years of application on the date of silking. Within the second year applications, surface applications increased the date of silking by four days under the Sc compost while in the first year surface applications increased the date of silking by two days with the Lc compost.

Ear Leaf Nitrogen

All treatments averaged at or below 2.5% N in the ear leaf (Appendix C.12). The leaf N in the control (2.5%) was not significantly different from the compost treatments' average concentration (2.2%). The source of compost material had no effect on ear leaf N for first time applications. After two years of application, Sc compost produced corn with lower ear leaf N than Lc. No effect of number of years of application was evident for the Lc material. There was higher leaf N concentration for incorporated compost (average 2.4%) compared with surface applied compost (2.1%).

Corn yield

Where corn received nitrogen fertilizer, there was no overall effect of compost on corn yields compared with the control (Appendix C.12). There was a significant interaction of compost, tillage, and years of application (Table 28). The second year application of Sc and first year of application of Lc composts had lower yields when left on the soil surface rather than incorporated into the soil. Provided the compost materials were incorporated into the soil there were no differences in the yields of corn due to the source of the material or whether one or two applications had been made.

Table **28.** **Effect of compost treatments on grain corn yield receiving fertilizer N at the clay loam site, 1995.**

	Years	Incorporated	Surface	Mean	Control
Sc compost	2	5576	3607	5079	5930
	1	5922	5213		
Lc compost	2	5829	6257	5815	
	1	6292	4883		
	Mean	5905	4990		

ANOVA P: Control=.133; Compost=.001; Tillage<.000; Year=.222; C x T=.050; C x Y=.001; T x Y=.496; C x T x Y=.001

Corn receiving no nitrogen fertilizer resulted in no differences in yield due to compost (Table 29). The grain yield averaged 2892 (±271) kg ha^{-1}. The yield response to N fertilizer, the delta yield, was not significantly different among treatments and averaged 2608 (±322) kg ha^{-1}.

Table **29.** **Effect of compost treatments on grain corn yield receiving no fertilizer N at the clay loam site, 1995**

	Incorporated	Surface	Mean
Sc compost	2866	2577	2722
Lc compost	3497	2821	3159
Mean	3182	2699	
Control		2513	
ANOVA P:	Control=.495; Compost=.299; Tillage=.254; Year=.426; C x T=.643; C x Y=.354; T x Y=.645; C x T x Y=.617		

The equation developed from the N response trial predicted a yield of 5665 kg ha^{-1}, at the rate of N which had been applied. The predicted yield was 5% lower than the yield of the control in the main trial, which received N, and 3% lower than the yield where Lc compost was applied with N fertilizer (Table 30). The average yield where Sc compost was applied was 12% lower than the predicted yield, but only 2% less if the second year surface applied treatments are ignored.

The measured grain yield of the control without fertilizer N was 42% higher than predicted by the response curve and 63% lower than the average yield of all treatments without fertilizer N. The residual N in the soil, evident from the yield where N was not applied, was not large and produced low grain corn yields.

Table **30.** **Summary of corn grain yield and nitrogen response, clay loam site 1995 (kg ha^{-1})**

Rate of N applied to trial	150
Recommended N application rate based on soil N test (PR=5)	146
MER-N (PR=5) from N response curve	286
Expected grain yield from N response curve at actual rate N applied	5665
Measured grain yield of control plots receiving N fertilizer	5930
Expected grain yield at zero-N level from response curve	1773
Measured grain yield of control plots not receiving N fertilizer	2513

Soil water content

Soil water content over the 0-80 cm depth remained higher than for the 0-20 cm depth throughout the season.

On several dates, differences in soil water content due to treatments in the upper soil layer (0-20 cm) were evident. Soil water content under Sc compost was higher than under Lc, but differences were small. Composts did not result in a higher overall water content than no compost. Over the June 9-20 period of soil drying, there was no suggestion of slower rate of drying under compost treatments. The drying coefficient averaged 0.03 (±.003) d^{-1}.

Measured over the 0-80 cm soil depth, water content was not found to be different among treatments.

The mean water content measured at the site in 1995 is shown in Figure 22.

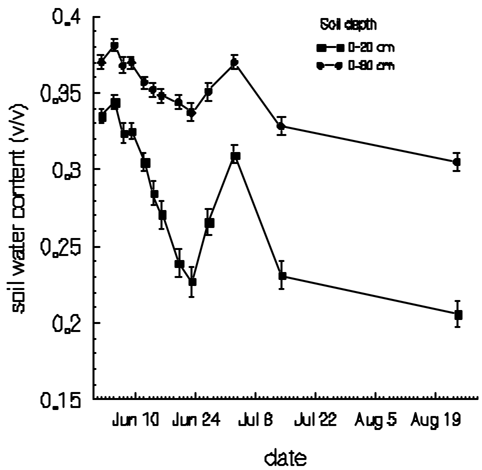

Figure 22. Mean soil water content at the clay loam site, 1995 (bars are standard error).

Soil solution

Chloride sampling indicated that the profile was not leached below 50 cm.

Solution samples from 30 cm contained low nitrate levels and averaged 5.1 mg L^{-1}, however, the treatment effects were not significant (Appendix C.14). DOC levels were higher under the control (95 mg C L^{-1}) than under compost treatments (56 mg L^{-1}) (Appendix C.15).

At 80 cm, levels of ammonium and nitrate were not influenced by compost application and averaged 0.4 mg NH_4-N L^{-1} and 3.7 mg NO_3-N L^{-1}. Levels of DOC were higher under the control (53 mg L^{-1}) than under composts (41 mg L^{-1}). However, a significant interaction showed that second year Lc applications had similar DOC concentrations as the control.

Orthophosphates were not detected in most samples.

Cu, Mn, Ni, or Zn were found in less than one quarter of samples extracted at either 30 or 80 cm depths (Table 31). Levels of Mn exceeded drinking water quality guidelines, of 0.05 mg L^{-1}, in all four samples where they appeared. These samples were all in association with compost treatments.

Table **31.** **Metals detected in solution samples (mg L^{-1}) at the clay loam site, spring 1996.**

Metal	# samples detected	Minimum amount detected	Maximum amount detected	Ontario Drinking Water Objectives (mg L^{-1})	Number of samples exceeding guideline
30 cm soil depth; total samples analyzed=31					
Mn	4	0.10	0.39	#0.05	4
Zn	7	0.10	0.26	#5	0
80 cm soil depth; total samples analyzed=33					
Cu	1	0.17		#1	0
Mn	4	.10	0.26	#.05	4
Ni	2	.07	.09	not established	
Zn	5	.09	.24	#5	0

‡ Source: OMOE, 1984

Soil microbial biomass carbon

At the sampling date near planting, where the composts were incorporated, Sc compost resulted in higher biomass (134 g C m^{-2}) than the Lc compost (103 g C m^{-2}), while for surface applications the two sources contained similar biomass C (Appendix C.17).

Compost did not increase the amount of microbial biomass C in June, however, in August there was an increase relative to the control. In August biomass C measured 96 g C m^{-2} in the top 15 cm of the control soil, and 135 g C m^{-2} where there was compost applied. However, differences between composts were also evident: the Sc resulted in higher biomass C than Lc, with averages of 152 and 118 g C m^{-2}, respectively. Differences in biomass C due to compost were significant for second year applications but not first year applications.

5.5.3 1996 Season

Soybean growth and development

Compost treatments had no significant effect on soybean emergence at this site in 1996. Measurements taken at 14 and 22 days after planting indicated soybean populations of 45.1 (±1.1) and 50.2 (±0.71) plants m^{-2}, respectively (Appendix C.10).

Soybean plant nodule weights were 35% lower in the absence of compost, than where compost had been applied (Table 32). The nodule weights averaged 345 (±34) mg plant^{-1} in the control treatment while nodule weights averaged 466 (±12) mg plant^{-1} with compost applications.

Differences between nodule weights due to compost type were greatest where the composts were incorporated. In this case, the Lc compost resulted in higher nodule weights than the Sc compost.

Table **32.** **Effects of compost applications on nodule weights (mg plant^{-1})**

	Incorporated	Surface	Mean	Control
Sc compost	429	477	453	345
Lc compost	506	453	479	

ANOVA P: Control=.004; Compost=.224; Tillage=.922; Year=.449; C x T=.027; C x Y=.786; T x Y=.976; C x T x Y=.051

Soybean yield

Soybean yield for the site averaged 3173 (±45) kg ha^{-1} (Appendix C.12). Incorporation of the compost materials reduced soybean yield relative to the surface application in the treatments receiving three years of compost (Table 33).

Table **33.** **Effects of compost treatments on soybean yield (kg ha^{-1}) at the clay loam site, 1996.**

Tillage	Number of years of compost application		
	1	2	3
Incorporated	3167	3087	3125
Surface	2990	3223	3420
Control	3219		

ANOVA P: Control=.700; Compost=.846; Tillage=.247; Year=.105; C x T=.120; C x Y=.720; T x Y=.038; C x T x Y=.213

Nitrogen content of the beans averaged 6.06 to 6.38 % for treatments, and 6.24 % (±.03) overall. There were no significant effects of treatments.

Soil water content

Soil water content in the upper (0-20 cm) soil depth appeared to be influenced by the compost type. Where the Sc compost was applied, regardless of years and incorporation, water content was slightly higher on the sampled dates. No similar or clear pattern of effects on water content over the 0-80 cm depth was detected.

Measured over a soil drying period, August 16-20, the drying coefficient tended to be higher for the control, than for the compost treatments (P=0.094), suggesting a trend of faster drying in the absence of compost (k= .049 d^{-1}), than in its presence (k= .030 d^{-1}).

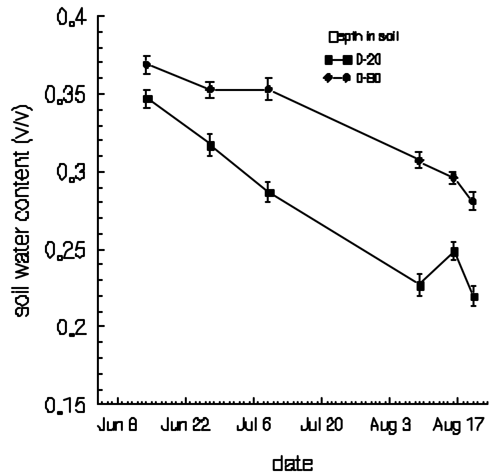

Figure 23. Mean soil water content at the clay loam site, 1996 (bars are standard error).

Mean seasonal water content is shown in Figure 23.

Soil solution

Compost treatments had no significant effects on levels of ammonium and nitrate in soil solution at 30 cm. They averaged 0.39 and 8.7 mg N L^{-1}, for the site, respectively (Appendix C.14).

DOC levels were highest under 3 years of compost left on the soil surface (26.7 mg L^{-1}). The control, for which only one value was obtained due to insufficient sample for analysis, was 19.5 mg L^{-1} (Appendix C.13).

Soil microbial biomass carbon

At sampling in June, biomass C under Sc compost (177 g C m^{-2}) was higher than under the Lc compost (140 g C m^{-2}). The control averaged 116 g C m^{-2}. In August, however, biomass C was higher with increasing years of compost application, averaging 122, 164, 216 g C m^{-2} for 1, 2, and 3 years, respectively, while the control averaged 143 g C m^{-2} (Appendix C.17).

Soil characterization

<u>Metal Content:</u>

Higher concentrations of total Co, Cr, and Ni in the 0-20 cm of soil were detected as a result of 3 years of compost additions (Table 34). While the differences were statistically significant, they were small, and the concentrations were less than (Co, Cr), or near (Ni), the concentration measured at the site in the 1993 baseline site characterization (Appendix C.3), suggesting that differences do not reflect compost applications. Nevertheless, the average metal concentrations were below the MOEE guidelines and usually near the Ontario average reported by Frank *et al.* (1976, 1979). No statistical differences in mean metal concentrations were detected at the 20-40 cm soil depth.

Table 34. Total metal concentration (mg kg^{-1}) in soil at clay loam site after 3 years of compost application.

	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Zn	As	Se
0-20 soil depth											
Control	<1	5.5	11.7	30.7	0.08	<2.5	11.3	19.3	110.3	3.5	<0.5
Sc compost	<1	7.2	12.7	28.7	0.06	<2.5	14.0	18.3	84.0	2.9	<0.5
Lc compost	<1	7.0	15.3	47.3	0.08	<2.5	13.3	33.0	141.3	4.0	<0.5
ANOVA P		.020	.016	.424	.519		.018	.341	.408	.354	
20-40 cm soil depth											
Control	<1	7.7	17.0	44.7	0.08	<2.5	16.7	25.7	134.3	4.7	<0.5
Sc compost	<1	7.0	13.0	27.0	0.05	<2.5	14.3	17.7	74.0	4.1	<0.5
Lc compost	<1	6.5	12.7	27.0	0.08	<2.5	12.3	16.0	65.7	3.2	<0.5
ANOVA P		.601	.159	.084	.277		.399	.542	.245	.291	
MOEE guideline[1]	3.0	25	50	60	0.15	2.0	60	150	500	10	2
normal[2]	0.56	4.4	14.3	25.4	0.11	1.65	15.9	14.1	53.5	6.3	0.370

1. Source: Waste Reduction Office, Ontario Ministry of the Environment. 1991. Interim Guidelines for the Production and Use of Aerobic Compost in Ontario. Queen's Printer for Ontario. pp. 7-8.
2. Source Frank *et al.* (1976, 1979). Based on 296 farm fields sampled to 15 cm soil depth (1976). Based on 30 samples, 15 cm soil depth (1979). Data are the mean of all soils sampled.

Soil fertility:

Soil test P levels were all ranked medium to high (corn) with a minimal fertilizer-P requirement (Table 37). Compost applications for 2 or 3 years resulted in a slightly higher soil test P level than the first year compost applications, particularly with the Sc compost.

Soil test K levels were medium to very high (Table 35). More than 1 year application of the Sc compost resulted in higher test levels than other treatments. Compost increased soil test K levels above the control and eliminated any requirement for potassium fertilization.

Table **35.** **Soil test P and K levels (mg L^{-1}) in the soil and fertilizer recommendation for corn (kg ha^{-1}) in relation to compost additions at the clay loam site.**

	Years	Soil test P	Recommendation P_2O_5	Soil test K	Recommendation K_2O
Sc compost	1	21	20	121	0
	2	26	20	179	0
	3	30	20	156	0
Lc compost	1	19	20	134	0
	2	25	20	127	0
	3	22	20	129	0
Control		19	20	110	30
ANOVA P (soil test levels)		Control=.103; Compost=.114; Year=.039; C x Y=.378		Control=.023; Compost=.030; Year=.094; C x Y=.035	

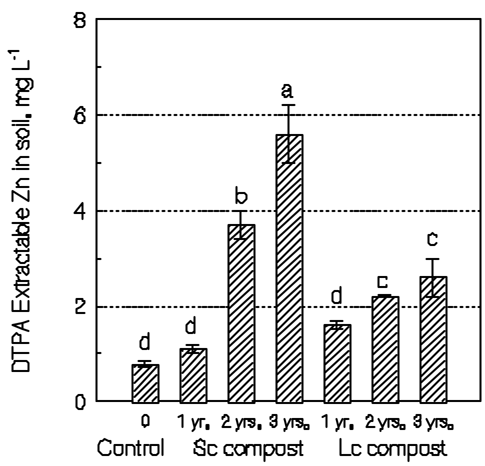

Figure 24. Effect of compost applications on DTPA extractable Zn levels measured in the soil at the clay loam site (standard error bars shown).

DTPA extractable Zn levels were lowest where compost was not applied and in the first year compost applications (Figure 24). Compost applications increased the extractable Zn, increasing most with the Sc compost. On average the Sc compost contributed 3.5 times as much total Zn by the compost applications as the Lc compost (see Appendix C.6).

No influence of compost applications were detected in the level of DTPA extractable Mn, pH, or electrical conductivity (Appendix C.19).

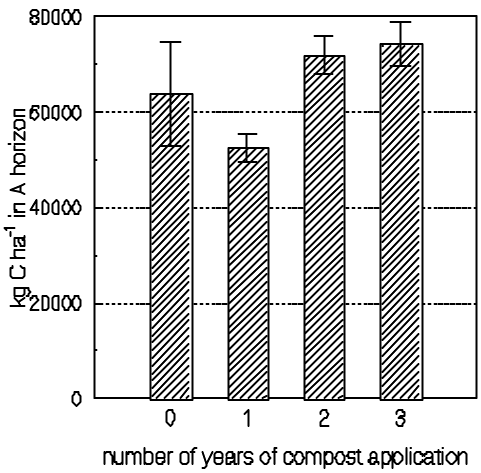

Figure 25. Organic C storage in A horizon at clay loam site (standard error bars shown).

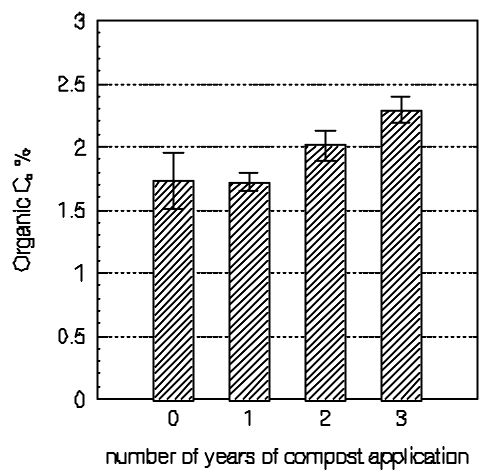

Figure 26. Concentration of organic C in the A horizon at the clay loam site (standard error bars shown).

Soil carbon:

Increasing years of application of compost resulted in increasing concentration of the organic C measured in the A horizon of the soil (Figure 25) (Appendix C.19). The total amount of organic carbon measured in the A horizon increased with increasing years of application of compost (Figure 26).

Soil physical properties:

The average water stable aggregates (WSA) ranged from 9.4 - 14.5%. The control averaged 12.4%, a value which was statistically greater than two of the compost treatments; the third year of Sc and the first year of Lc applications, where WSA was 9.4%.

A summary of the hydraulic parameters measured with the GPI and undisturbed cores are given in Table 36 (see Appendix C.21).

The addition of compost resulted in a significant increase (P=0.087) in the total porosity of the soil and a decrease in bulk density as measured by core samples. The data at this site were more variable than at the loam site. Data from the undisturbed core measurements for the Lc compost after 2 years of application appear to be outliers. The data for the individual replications of this treatment are quite variable (Appendix C.21). For example, the porosity for this treatment varied from 0.335 to 0.505 $cm^3 cm^{-3}$ for individual cores. No significant difference between compost type on total porosity was measured.

Total porosity generally increased with increasing number of years of application of compost. However, the interaction between compost type, year of application and effective pore size distribution was not as significant as it was at the loam site. At this site, application of both the Sc and Lc compost resulted in a significant increase in residual water after only one year of application. However, similar to the loam site, the Sc compost resulted in an increase in residual water content for the second and third years of application, while the Lc compost had little subsequent effect after the first year. In fact, given the variability in the Lc plots, no trend in residual water content with years of application is present.

Table 36. Summary of surface hydraulic properties measured with the Guelph Pressure Infiltrometer and undisturbed cores at the clay loam site.

Compost Application (yrs)	Bulk Density ($g cm^{-3}$)	K_S** ($cm hr^{-1}$)	K_F*** ($cm hr^{-1}$)	Soil Water Content ($cm^3 cm^{-3}$)			
				h*=0	h=10 cm	h=333 cm	h=15,000 cm
0 (check)	1.58	3.06	9.76	0.432	0.378	0.313	0.264
Sc compost							
1 yrs	1.47	0.39	8.16	0.460	0.406	0.344	0.308
2 yrs	1.45	25.35	13.74	0.516	0.414	0.350	0.310
3 yrs	1.37	0.51	25.4	0.506	0.451	0.400	0.364
Lc compost							
1 yrs	1.39	0.21	11.88	0.488	0.432	0.377	0.327
2 yrs	1.36	36.15	23.70	0.428	0.358	0.297	0.246
3 yrs	1.33	8.62	31.14	0.526	0.458	0.385	0.326

* h = soil matric pressure head
** K_S = saturated hydraulic conductivity
*** K_F = field saturated hydraulic conductivity

The influence of compost type after three years of application on particular pore size categories is summarized in Table 37.

The two composts resulted in different changes to specific pore size categories. The Lc compost increased the macropore, drainable, and plant available porosity. The three year application of the Sc compost resulted in a decrease in the macropore, drainable, and plant available water porosity, however, it did increase the residual water content.

Table 37. Influence of three years of compost application on soil pore size categories at the clay loam site.

Pore Size Categories	Soil Water Amounts (%)		
	No compost	Lc compost	Sc compost
Residual	26.4	32.6	36.4
Plant Available	4.8	5.9	3.6
Drainable	6.5	7.3	5.1
Macropore	5.4	6.8	5.5
Total Porosity	**43.2**	**52.6**	**50.6**

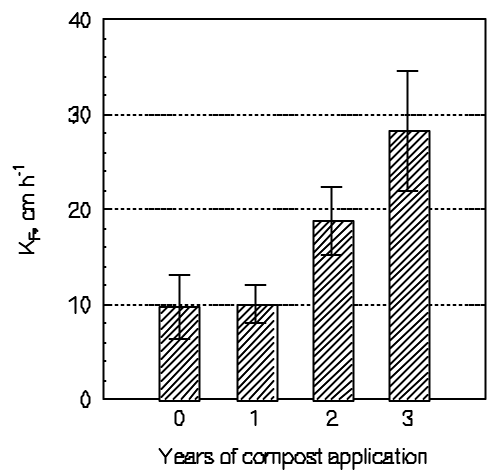

Figure 27. Effect of years of application of compost on field saturated hydraulic conductivity at the clay loam site (average of both composts).

The K_F values significantly increased with compost application and the effect increased with increasing years of application for both compost types (Figure 27). The K_S data are quite variable and show no clear treatment effects.

6. DISCUSSION - COMPOST USE ON AGRICULTURAL LAND

6.1 Crop Growth and Yield

Initial laboratory bench top emergence and growth studies indicated delayed emergence may occur if the application rate exceeded 2.5 cm in depth (average 165 Mg wet ha^{-1}), for the two materials selected for the field experiments. Therefore the application rate for the main field experiment was restricted to 100 Mg ha^{-1}. Nevertheless there were indications that early emergence of corn may be restricted by compost application, particularly the Sc material (Appendix B.1). The restriction may be attributed to the high EC of the material which would be quickly dissipated under field conditions and normal rainfall.

The climatic data collected at each site (Appendix C.8) were useful in comparing the three seasons and the two sites, which are within approximately 10 km of one another, but subject to different rainfall distribution. The moisture deficit was less at the loam site than the clay loam site in 1994 due to higher rainfall and lower potential evapotranspiration. The sites were rather similar in 1995 and 1996 (Table 38). In 1996 rainfall approximately equalled the potential evapotranspiration at both sites, however, rainfall was in excess of evapotranspiration over the four month period of June through September. The 1996 season, therefore, could be considered to be abnormally wet.

Table **38.** **Rainfall and Potential Evapotranspiration (mm) for loam and clay loam sites for the months of June to September inclusive**

Site	Year	Rainfall	Evapotranspiration	Moisture Deficit
Loam	1994	220	352	-132
	1995	237	498	-261
	1996	458	440	18
Clay loam	1994	168	386	-218
	1995	266	500	-234
	1996	421	415	6

Differences between years are further demonstrated by examining silking dates and the early season rainfall (Table 39). High June and July rainfall in 1996 led corn to reach silking between 4 to 12 days later than in the previous two years.

Table **39.** **Dates of corn silking and June-July rainfall at loam site for 1994, 1995, and 1996**

Year	Planting date	Silking date	Silking, days after planting	June + July rainfall, mm
		range of means for treatment		
1994	May 30	August 2 - August 6	65 - 68	81‡
1995	May 20	July 26 - July 27	67 - 68	82
1996	June 3	August 14 - August 19	72 - 77	241

‡ rainfall measurements started June 14 in 1994

Where standard nitrogen fertilizer practices were followed in the main trial, compost increased the corn yield in 1994 and 1995 at the loam site (Table 40). At the same site in 1996, however, when corn yields were low, compost had no influence on yield. However, yields were influenced by compost management in 1996 at this site, where incorporating the composts into the soil increased yields by 14% over surface applications.

The influence of composts in the absence of N fertilizer was measured in 1995 and 1996. At the loam site the average effect of compost was to not alter the yield relative to the control. Nevertheless, in 1995, the yield of corn with Lc, but not the Sc compost, increased yields relative to the control when the crop was grown in the absence of N fertilizer.

At the clay loam site, grain yields were reduced due to compost applications in 1994 (Table 40). The yield reduction was due to a large yield suppression of the Sc compost rather than the Lc compost. In 1995 the Lc compost continued to produce higher yields than the Sc compost. In the absence of N fertilizer, in 1995, the composts did not reduce corn grain yields.

The 1996 soybean yields at the clay loam site were not influenced by compost applications. However, the evidence suggested that compost increased soybean nodule weight per plant suggesting improved potential nitrogen nutrition for soybean growth with compost.

Table **40.** **Effect of compost on relative crop yields in the main trial (compost yield/control yield, %) with N fertilizer (corn).**

Site	Year	Crop	Sc Compost	Lc Compost	Yield of control, kg ha^{-1}
Loam	1994	corn	115	116	6908
	1995	corn	106	110	8659
	1996	corn	97	110	3861
Clay loam	1994	corn	67	89	7320
	1995	corn	86	98	5930
	1996	soybeans	98	99	3219

Similarly, grain corn yields and soybean yields in the rate study showed no yield suppression due to compost applications at rates as high as 300 Mg ha^{-1}. In fact increases in yields due to composts were evident with some applications. The highest yields of corn with or without N and of soybeans were produced at the highest rate of fall applied Sc compost.

Higher crop yields were often predicted by crop measurements made earlier in the growing season. For example, in the rate trial, the corn with higher yields also reached fourth leaf and silking sooner, and were taller at fourth leaf. Soybeans in the same trial had not only improved plant stand, but also flowered earlier and plants were taller at flowering. In the main trial, higher yields were often a reflection of earlier silking dates.

6.2 Soil Quality

6.2.1 Soil Fertility

Methods to determine extractable forms of elements, including P and K, have been developed for mineral soils to provide an index of plant available nutrients from which predictions of the amount of fertilizer P and K may be made for optimum crop production. However, the methods are not necessarily suitable for determining the use of organic materials. Organic materials, including sludge and compost, however, can be considered as very dilute organic fertilizers, thus total analysis may be used for interpretation of their nutrient value (Table 41).

Total P additions in the compost averaged 122 kg P ha^{-1} yr^{-1} for the Sc compost, and 82 kg P ha^{-1} yr^{-1} for the Lc compost. The amount of total P applied in the Sc compost was linearly related to the amount of $NaHCO_3$-extractable P measured in the soil at the end of the study (Figure 28). The slope of the relationship for the Sc compost for both sites overall suggested that for every 100 kg ha^{-1} total P applied in compost, an additional 3.8 mg L^{-1} of soil test P was measured in the soil. The relationship also suggests that 11 years of the management used in this study would be required before excessive levels of soil test P were reached.

A similar relationship could not be established for the Lc compost, where the linear relationship was not significant with values for R^2 of .290 and .062 for the loam and clay loam sites, respectively.

The additions of three years of compost (Table 42), result in a 30 kg ha^{-1} credit for P_2O_5 at the loam site, but no credit relative to the control at the clay loam site, despite the increase in the test level from 19 in the control to 30 mg L^{-1} where the Sc compost was applied. The Lc compost provided 49% less P to the soil and raised the soil test P less than the Sc compost.

Table **41.** **Linear effects of soil test P, K, and Zn in soil versus the amount of total P, K, Zn applied in composts (Y vs X)**

Site	Compost	n	Soil test P				Soil test K				Soil test Zn			
			a	**b**	**r**	**P#0.05?**	**a**	**b**	**r**	**P#0.05 ?**	**a**	**b**	**r**	**P#0.05 ?**
loam	Sc	12	16.0	.0375	.752	y	88.1	.0378	.769	y	1.11	.120	.941	y
	Lc	12	14.1	.0311	.538	n	73.5	.0354	.622	y	1.25	.126	.877	y
	both	21	14.2	.0403	.723	y	81.8	.0391	.760	y	1.31	.116	.939	y
	both using means	7	14.4	.0398	.880	y	82.0	.0389	.820	y	1.31	.115	.983	y
clay loam	Sc	12	18.7	.0304	.681	y	121	.0212	.519	n	.545	.098	.969	y
	Lc	12	19.2	.0184	.250	n	119	.0149	.190	n	1.02	.117	.888	y
	both	21	18.3	.029	.513	y	121	.0197	.453	y	1.01	.089	.940	y
	both using means	7	18.0	.0299	.877	y	121	.0198	.629	n	.994	.089	.973	y
Sc compost, both sites		24	16.3	.0383	.781	y	105	.0295	.637	y	.829	.109	.923	y
Lc compost, both sites		24	16.7	.0248	.358	n	96.5	.0252	.282	n	1.14	.121	.866	y
both sites, composts, using means		14	16.2	.0348	.848	y	102	.0293	.666	y	1.15	.344	.957	y

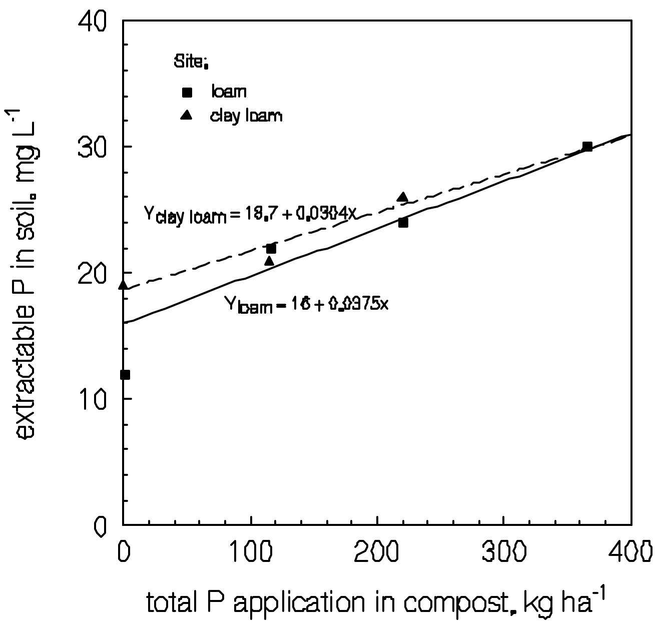

Figure 28. Relationship between the amount of total P added in Sc compost and the concentration of $NaHCO_3$ extractable P measured in the soil at both sites.

Table **42.** **Soil test P levels (mg L^{-1}) and fertilizer requirements for corn (kg P_2O_5 ha^{-1}) for the control and three years of compost applications**

	Loam site		Clay loam site	
	soil test P	**fertilizer requirement**	**soil test P**	**fertilizer requirement**
Control	12	50	19	20
Sc compost (3 yrs)	30	20	30	20
Lc compost (3 yrs)	20	20	22	20

In both composts the content of total K was higher than that for the total P. Annual additions of total K from compost averaged 300 kg K ha^{-1} yr^{-1} for Lc and 752 kg^{-1} K ha^{-1} yr^{-1} for Sc compost. Although large amounts of total K were added to the soil by composts the amount applied was not closely linked to the amount of exchangeable K in the soil at the clay loam site, where R^2 values of .270 and .036 for Sc and Lc composts, respectively, were calculated. At the loam site, on the other hand, the relationship between total K added in composts and exchangeable K in soil was linearly related for both compost materials (Figure 29). At the loam site the relationship indicated that 1000 kg ha^{-1} of total K applied in either compost resulted in an additional 39 mg L^{-1} measured in the soil test.

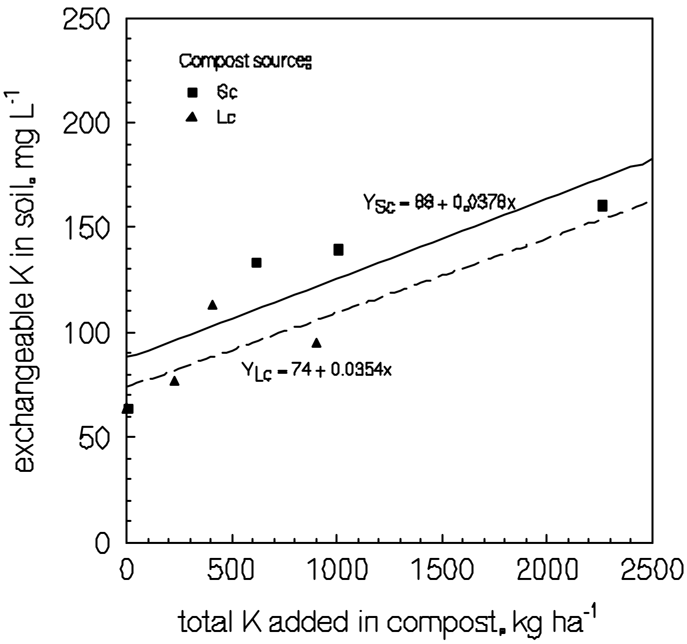

Figure 29. Relationship between the amount of total K added in Sc and Lc composts and the concentration of NH_4COOH extractable K measured in the soil at the loam site.

Compost additions increased the soil test (exchangeable) K levels (Table 43). At the loam site, the increase in the soil test K provided a credit of 80 kg K_2O ha^{-1} after 3 years of Sc compost additions but only 30 kg K_2O ha^{-1} where Lc was applied, a compost providing 60% less total K. At the clay loam site, the fertilizer credit was 30 kg ha^{-1} after 3 years of compost additions for both materials.

Table **43.** **Soil test K levels (mg L^{-1}) and fertilizer requirements for corn (kg K_2O ha^{-1}) for the control and three years of compost applications**

	Loam site		Clay loam site	
	soil test K	**fertilizer requirement**	**soil test K**	**fertilizer requirement**
Control	64	80	110	30
Sc compost (3 yrs)	161	0	156	0
Lc compost (3 yrs)	95	50	129	0

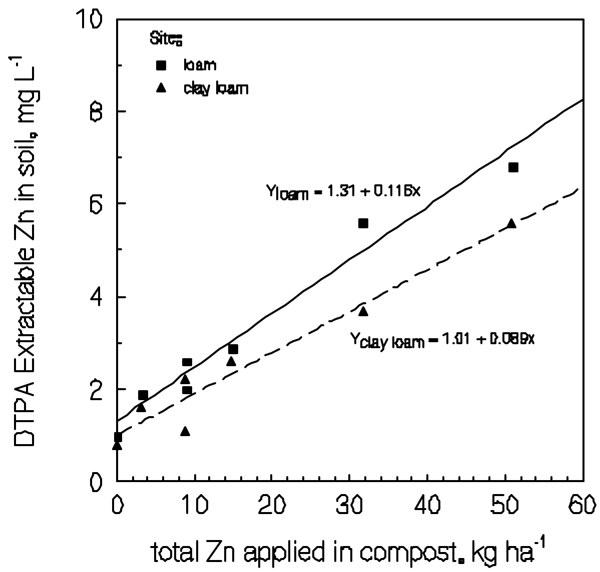

Figure 30. Relationship between total Zn applied in Sc and Lc composts and the DTPA extractable Zn concentration measured in the soil at both sites.

Annual additions of total Zn from compost averaged 5 and 17 kg ha^{-1} yr^{-1} for Lc and Sc composts, respectively. The additions of composts resulted in substantial increases in the extractable Zn in the soil and also elevated the Zn to levels preferred for corn production (Figure 30; Table 44). As a result the potential for zinc deficiency at both locations was reduced to zero by both compost materials.

At the loam site slopes of the relationship were .120 and .126 for Sc and Lc composts, respectively, while at the clay loam site slopes were .098 and .117, respectively. The mean relationship for each site is depicted in Figure 30.

Table **44.** **DTPA Extractable Zn levels and Zn Index for corn for the control and three years of compost applications**

	Loam site		Clay loam site	
	soil test Zn, mg L^{-1}	**Zn Index‡**	**soil test Zn, mg L^{-1}**	**Zn Index‡**
Control	0.99	13	0.78	12
Sc compost (3 yrs)	6.8	39	5.6	33
Lc compost (3 yrs)	2.9	22	2.6	20

‡ Zn index = 203 + 4.5(DTPA extr.Zn in mg L^{-1}) - 50.7(soil pH) + 3.3$(\text{soil pH})^2$
values of Zn Index <15: Zn is likely to be deficient for corn.

6.2.2 Nitrogen

In the compost application rate study, there was no change in the nitrate-nitrogen soil test levels resulting from the fall compost application. Where N fertilizer was applied there was adequate N in the ear leaf when measured at silking. Composts produced similar response when adequately fertilized with N as evident by the consistent delta yield values for the trial. This evidence suggests that compost did not immobilize soil nitrogen. The highest rate of spring applied compost produced yields 6% lower than those predicted by the response curve at the rate of N applied and also without N fertilizer, suggesting that N availability may have been affected at this rate for a spring application.

In the comparison of compost-nitrogen relations in grass hay, a very nitrogen sensitive crop, no evidence of yield suppression was evident where 170 Mg wet ha^{-1} of compost was applied in the spring. In fact where adequate nitrogen was applied to realize the yield potential of the hay, a nitrogen response of 32% was increased to 55% where compost was applied. At the second cut of hay, a 31% increase in dry matter production where compost but not nitrogen fertilizer was applied suggests some N was made available to the crop from the compost or the soil. However, the gain in yield was 78% due to compost where N fertilizer had been applied in the spring, suggesting that compost increased the fertilizer use efficiency of the spring nitrogen application.

In the main trial, fertilizer N was applied at a uniform rate to all treatments rather than providing differential rates according to the N content of the compost. The approach was used to provide a direct measurement of the effect of compost where nitrogen was adequate for corn production. In the 1995 and 1996 seasons, additional information concerning the compost - nitrogen relations in corn was obtained by leaving an area in each plot to which no fertilizer-N was applied and assessing the N nutrition of the corn plants with plant tissue testing where N was applied.

The compost materials contained an average of 12 kg $(NH_4 + NO_3)$-N ha^{-1} yr^{-1} for Lc compost and 3 kg $(NH_4 + NO_3)$-N ha^{-1} yr^{-1} for Sc compost in 50 Mg dry compost ha^{-1} yr^{-1}. The total N application was 530 and 628 kg N ha^{-1} yr^{-1} for Lc, and Sc composts, respectively.

At the loam site in 1994, the yield of corn produced with composts and N fertilizer was similar to the yield predicted by the N response curve at the rate applied to the field, indicating compost did not diminish the availability of the N in the fertilizer. The response curve data also pointed to suitable choice of the rate of N to be applied to the site, where the MER-N was similar to that applied.

On the other hand, at the clay loam site in 1994, the yield of corn which received compost was lower than what was predicted from the response curve at the rate applied to the field, and lower than that in the control which had received N, suggesting that compost reduced the availability of fertilizer N and hence, yields. Data from the response curve also indicated that nitrogen fertilizer was applied below the maximum economic rate.

In 1995, at the loam site, ear leaf tissue analysis showed adequate N nutrition. Yields were higher or near those in the controls in the presence of compost, either with or without fertilizer N. Measured yields were similar or exceeded those predicted by the response curve. The absence of a consistent overall increase in yield due to compost in the absence of fertilizer N suggests that little or no N was made available from the composts. However, a significantly higher yield in Lc compared with Sc amended soils in the absence of fertilizer N may be linked to the higher available N from the Lc compost, even though there was less total N applied in Lc than in Sc compost. Overall, the data suggest that compost did not limit N availability.

In 1995 the clay loam site received a higher rate of fertilizer N than in 1994, but the maximum economic rate proved to be higher than in 1994 and higher than the rate applied. Indeed, two thirds of the plots had inadequate N nutrition according to results of leaf tissue tests. On the other hand, compost applications did not reduce average yields relative to the controls, with or without fertilizer-N. Likewise, the yields were similar to that predicted by the response curve at the rate of fertilizer N applied. It is suggested that N uptake may have been limited at this site by adverse soil conditions or availability of soil N, however, N availability was not limited by compost applications.

In 1996, corn was grown at the loam site only. Adverse cold and wet weather conditions delayed emergence and prevented timely weed control. Rainfall exceeded potential evapotranspiration for the period of June to September in 1996, increasing the potential for N to be leached from the soil. Thus ear leaf N analysis indicated a deficiency of N for all treatments.

The 1996 N response indicated that inadequate levels of N were used to maximize yield. The yields measured in compost-amended soil exceeded those predicted from the N response curve at the rate of fertilizer N applied or where no fertilizer N was used. These points suggest compost was not contributing to the lack of N.

Further information concerning soil N at the loam site in 1996 will be provided through the thesis work of a graduate student working at this site. This should furnish a clearer understanding of the potentially mineralizable N in the soil due to successive years of application of the composts.

6.2.3 Soil Carbon

Annual additions of compost which amounted to approximately 10,000 to 15,000 kg C ha^{-1} yr^{-1} increased the organic C levels in the soil. On both the loam and clay loam sites, concentrations of organic C were 33% higher after 3 years of compost additions, relative to where no compost was applied.

The increases amounted to approximately 17 and 10 tonnes ha^{-1} more total organic C in the A horizon of the loam and clay loam soil, respectively, as a result of 3 years of compost addition, which is roughly one third the amount of organic C applied as compost over the period.

The relationship between the amount of organic C added in the compost materials, and the percent organic C measured in the soil is shown in Figure 31. Both sites had similar 1993 baseline organic matter levels in the 0-15 cm soil depth, of 3.3% organic matter. Figure 31 shows that at both sites, organic C in the A horizon where no compost was applied, was 1.7%. Additions of 41,000 kg compost C ha^{-1} achieved after three consecutive years of application of compost, increased the A horizon C content to 2.3%.

6.2.4 Soil Physical and Hydraulic Properties

The undisturbed core data clearly indicate a significant difference in the interaction of the two compost types and the soil matrix. The Sc compost at both sites resulted in a decrease in the amount of large pores, but a significant increase in total porosity compared to the untreated soil. The increase in total porosity from the Sc compost application was caused by a very high increase in the residual water content porosity; that is, very small pores that hold water at greater than 15,000 cm of pressure head. The amount of this fine pore size category was increased with each year of added Sc compost at both sites. The data suggest that the compost material is either biologically active, and results in the organic material being progressively more bound to the clay sized fractions with time, or the Sc material is very hydrophilic.

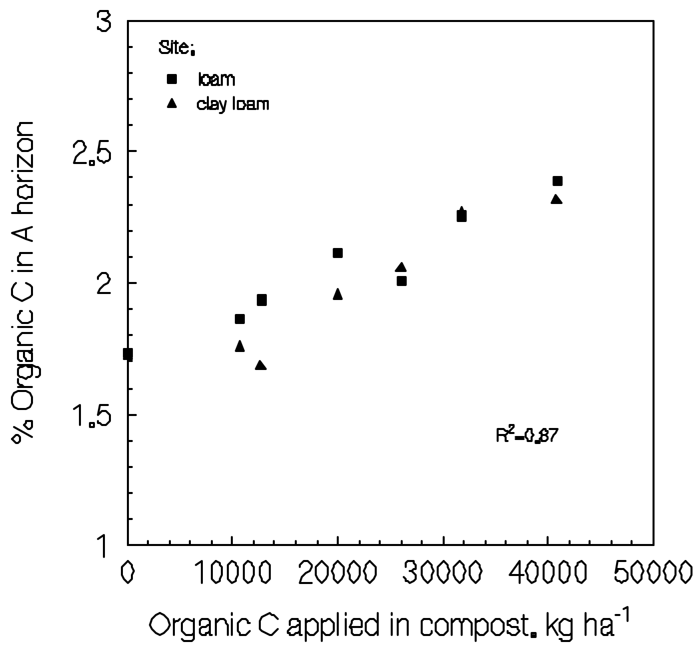

Figure 31. Relationship of amount of organic carbon added in compost materials and the concentration of organic C measured in the A horizon at both sites.

In contrast, the Lc compost resulted in a slight increase in the amount of larger pore sizes, along with an overall increase in the total porosity compared to the untreated soil. The total porosity increase was smaller than that caused by the Sc compost. The influence of the Lc compost on the very small pores - residual water porosity - was negligible at the loam site and variable at the clay loam site. This was in marked contrast to the Sc compost.

In addition, infiltration was increased by both composts at the clay loam site and the bulk density decreased. These findings suggest that the addition of composts significantly reduces the risk of soil loss due to water erosion by permitting more rapid infiltration of rainfall into the soil surface.

6.3 Compost Management

Successive years of application of compost had little effect on plant development and yield. However, increasing years of compost application showed a benefit in soil quality as measured by increases in soil carbon, soil P, K, and Zn, and some evidence of decreasing soil density and increasing infiltration.

Requirements for the incorporation of the compost, however, were seldom evident. However, in 1996 corn grown at the loam site developed more rapidly and reached silking earlier where compost was incorporated. In the wet soil conditions of 1996 the compost which was not incorporated slightly aggravated corn production compared with where compost was incorporated; ear leaf N was higher, and yield of corn, with or without N, was higher where composts were incorporated rather than left on the soil surface.

A higher plant stand was achieved in 1994 where composts were not incorporated at the clay loam site but incorporation had no influence on corn development and yield. At this site in 1995, ear leaf N was higher where the compost was incorporated rather than left on the soil surface and corn yields were more consistent and higher where the compost was incorporated. The need for incorporation was only evident where fertilizer N was applied.

Soil water content measurements in the 0-20 cm soil depth did not indicate that the incorporation of the material would change the rate of drying of the soil. In fact, soil water content was not usually influenced by compost applications in the main trial. On the other hand, a single measurement made in the soybean rate trial showed that the 300 Mg ha^{-1} compost rate significantly increased soil water content in the 0-15 cm soil depth, relative to the bare soil.

In addition, measurements of erosion loss did not support a need for incorporation of compost.

In the 1995 rate trial, surface applications proved to be suitable for corn and soybean production. At the highest rates of application, of 300 Mg (wet) compost ha^{-1}, the compost was more likely to act as a mulch, and in the soybean trial this effect was shown to substantially reduce the failure to emerge due to soil crusting, and to suppress weeds. The depth of compost at the high rate would be approximately 5 cm. On the other hand, lab tests had shown that very high application rates of 6.4 cm, or approximately 314 Mg ha^{-1} reduced final emergence of corn and soybeans. The difference between results in the lab and field experiments at high application rates may be due to the tillage and incorporation in the seed row accomplished by the no-till planter in the field, hence minimizing potential negative effects of high rates of application. The results suggest that if compost were applied after planting at high rates emergence of the crop may be delayed.

Applications of compost to a mixed species grass hay, where incorporation is not an option, may result in some species suppression, although species recovery was possible, and the overall effect of compost was to increase dry matter production. It is possible that a light harrowing may reduce the smothering of some species.

In the main trial, all composts were applied in the spring and at rates of 100 Mg ha^{-1}. In the rate study, however, fall applications of compost were clearly preferred at high rates of application of around 300 Mg ha^{-1}. The reason for this is not clear from these studies. However, the high total salts measured in the Sc compost used in this study, and in the elutriate prepared from compost of the same source used in the laboratory test, may have contributed to the absence of the yield increase in the spring applications to the extent of the fall applications. It is possible that while salts were leached from the compost applied in the fall, during the winter, that there was insufficient time for the removal of salts from the spring applications.

6.4 Environmental Quality

The composts used in the study were materials which can be obtained for unrestricted use in land application. It is unclear the reasons for the relatively high levels of Ni, Cd, and Cr found in both composts used in the first year of the study but not subsequent years. The Sc compost also contained high levels of Cu in 1994 and 1995. Levels of metals in the compost samples exceeded compost quality guidelines (OMOE, 1991), for Cd and Cr for both composts in 1994, and for Cu in the Sc compost in 1994 and 1995. Electrical conductivity showed high (>3.5 mS cm^{-1}) levels of soluble salts in both composts in 1995 but not 1994 or 1996. SAR values for Sc compost were high (>5) in 1995 and 1996, but as Halet *et al.* (1996) point out, SAR was originally devised as an index for designating the sodium hazard of irrigation waters applied to soil, and that the usefulness of SAR for compost characterization is unresolved.

Soluble salts in the soils were low at both sites after compost applications. Metals in the soil were not significantly elevated. Hence there was no evidence that compost applications diminished soil quality. Similarly, the evidence of compost effects on soil biology suggested there was no decline in environmental quality as reflected in soil microbial biomass C in the soil.

Copper, manganese, zinc or nickel were found sporadically among solution samples obtained at one sampling date. Cu, Mn, and Zn water quality objectives relate to aesthetics, rather than health and there is no objective for Ni. Levels of Mn in several samples at both sites exceeded guidelines for drinking water quality. In all but one sample where this occurred, it was in association with compost treatments. Mn levels in compost are not restricted by the guidelines. Mn solubility fluctuates substantially over time in any particular soil because of its extreme sensitivity to soil drainage conditions (McBride, 1994). This fact and the occurrence of Mn in association with one control sample, suggests that the elevated levels may not be due to compost. However, the presence of high Mn levels in compost elutriates used in the seed germination tests may suggest further information on Mn in composts is warranted. Mn is an essential trace element to all organisms and has low to moderate phytotoxicity (McBride, 1994).

Trends towards lower nitrate levels in soil solution under compost applications were evident in the first year of the study but not in subsequent years at both sites. There is no evidence, therefore, that compost applications contribute to increased nitrates which may potentially leach to subsurface water supplies. In 1995 there was a trend towards lower dissolved organic carbon levels under compost applications. Ontario's drinking water quality objectives (OMOEE, 1994) state a limit of 5.0 mg L^{-1} of DOC in water related to the aesthetic quality of the water, and all solution samples exceeded this concentration.

6.5 Economics

The application of compost to agricultural land results in many tangible, as well as intangible, benefits. Using those tangible benefits which have been demonstrated in this study a brief analysis is presented to determine the economic benefit to the farmer of using compost as a production input.

The data from the loam site was used in the analysis because of the lower variability of the data. The cost of the finished, screened composts delivered, was approximately \$45 Mg^{-1}. At an application rate of 100 Mg ha^{-1}, the cost of compost could not be justified based on yield increases and fertilizer benefits (Table 45). Furthermore, the total tangible benefits of using the compost were insufficient to cover the cost of the application.

The intangible benefits of organic carbon, improved water characteristics, and others, however may be sufficient to justify the application of the compost if it were delivered to the farm free of charge.

Table **45.** **A comparison of the debits and credits associated with the use of compost at the loam site over a three year period.**

Debits		Credits	
Material Cost ha^{-1}		Corn Yield*	
300 Mg @ $45/Mg	$13,500.00	1994: 1.051 Mg	$157.65
		1995: 0.726 Mg	$108.90
Application Cost, ha^{-1}		1996: 0.116 Mg	$17.40
2.47 hr ha^{-1} @$75 hr^{-1}	$555.00		
		Phosphorus	
Total Debits	$14,055.00	30 kg P_2O_5/ha/yr**	$79.20
		Potassium	
		80 kg K_2O/ha/yr***	$98.40
		Zinc	
		2.25 kg Zn/ha/yr	$29.70
		Total Credits	$491.25

*Corn valued at $150 Mg^{-1}
** 0-46-0 valued at $405.00 Mg^{-1}
*** 0-0-60 valued at $245.00 Mg^{-1}
Fertilizer contribution based on that measured after 3 years of application but assumed to last for 3 years.

Using financial models based on a potential residual nitrogen response from compost, Hyatt (1995) demonstrated that compost could be a financially viable production input after seven years of application if received at the farm at no cost. The model was based on compost containing 1.2%N and applied at a rate to provide 168 kg N ha^{-1} yr^{-1} which would mineralize at a rate of 10% per year. Hyatt's analysis was based solely on justifying compost use based on residual nitrogen mineralized from the compost. In our studies the contribution of nitrogen from composts was not significant.

7. CONCLUSIONS AND RECOMMENDATIONS

The increasing trend towards the composting of organic wastes will increase the pressure for rural lands to become the safe end-user for the compost rather than landfilling the material. This study confirms that compost, free of excessive metal contamination, can be safely applied to agricultural lands with potential benefit to soil quality and without impairing water quality. The findings of this study provide some understanding of the appropriate management and expected benefit of compost use in commercial agriculture.

1. Normal nitrogen rates may be used in conjunction with compost applications. However, a reduction in phosphorus and potassium fertilization may be considered. Since compost sources vary in their ability to elevate soil test levels in relation to the amount of total P they contain, generalizations can not be made concerning nutrient availability, thus regular soil testing should be used to determine requirements for P and K.

2. Further information is needed to assess the contribution of N mineralized from the composts over time to establish whether a nitrogen credit may be warranted.

3. Application rates in the order of 100 Mg ha^{-1} are suitable for land in the production of corn, soybeans and all grass hay. Application rates may be as high as 300 Mg ha^{-1} although at this level, the material may behave as a mulch.

4. Applications should be made in the fall rather than the spring. The studies which provided this comparison clearly showed the preference for fall applications for both corn and soybeans. The timing may be most important for application rates exceeding 150 Mg (wet) ha^{-1}, since spring applications to corn, soybeans, and hay at rates up to 170 Mg compost ha^{-1} in the other field trials often produced positive effects on crop performance.

5. Heavy duty planters with some in row tillage are necessary for planting corn and soybeans where compost application rates are heavy.

6. There is no need for incorporation of compost where the slope of the land does not exceed 4-6%.

7. Compost has the potential to increase water holding capacity and improve soil infiltration rates, thereby reducing risks of soil loss due to water erosion. The increased residual water content with the Sc compost, however, may increase the risk of delayed drainage and wet spring conditions. The impact of compost application on soil pore size distribution needs to be further investigated.

8. At application rates of 100 Mg ha^{-1} yr^{-1}, substantial increases in the organic carbon content of the soil were evident after only three years. This suggests composts may have a role in remediation of disturbed or eroded soils.

9. Improvements in crop performance, including increases in crop yield, with the use of composts may be expected to occur sometimes. The effects appear to relate to improved fertilizer N use efficiency, provision of macro- and micro- nutrients, and possibly to changes in hydraulic characteristics of the soil.

10. Finished food and yard waste compost application to agricultural land does not present environmental concerns from the perspective of soil and water quality, as measured in this study.

11. An economic justification for the use of composts in commercial agriculture is not evident, based on the simple evaluation used in this study. However, since benefits to soil have been clearly demonstrated, a farmer might justify expending the cost of application of the material if it were delivered to the farm for free. Composts might be most valuable when used to increase the production potential of eroded or disturbed surface soils.

12. The bench marked field sites provide an opportunity to obtain additional data on soil test levels. It would be useful to monitor the soil test levels at these sites in the future thereby establishing the fertility value of the compost applications to the farmer. To further evaluate the long term effects of the currently imposed treatments, continuation of the existing trials for an additional three years is recommended.

13. Further understanding of the physical and chemical properties of the compost and corresponding impacts on the physical, chemical, and biological characteristics of soil when the compost is applied is needed to allow farmers to decide on the suitability of using a particular compost for a specific soil.

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APPENDIX A

Appendix to Section 2

A.1 Analysis of Compost Materials Used in Benchtop Studies
A.2 Analysis of Elutriates prepared from compost sources
A.3 Lettuce seed germination in compost-sand mixes
A.4 Density and Moisture Content of Compost Materials used in studying effects of compost type and rate on corn emergence
A.5 Application Rates of Compost Materials used in studying effects of compost type and rate on corn emergence
A.6 Effects of compost application rate on emergence of corn
A.7 Compost Depths and Application Rates used in studying effects of compost rate on soybean emergence

A.1 Analysis of Compost Materials Used in Benchtop Studies (Sections 2.2, 2.3, 2.4)

parameter	units, dry wt basis	Gu	Lc	Sc	He	MOEE Compost Guidelines
dry matter	%	57.88	42.03	59.24	69.71	moisture content typically 30-
EC, sat'd paste	mS/cm	0.84	1.45	5.58	4.42	<3.5 [1]
Water soluble Cl^-	mg/L	79.8	107.7	571.7	246.7	
Exchangeable Na^+	mg/L	41.7	38	350	63.8	
Exchangeable	mg/L	21.9	23.8	161	230	
Exchangeable Ca^{2+}	mg/L	66.6	158.9	683	480.6	
SAR		1.14	0.75	3.14	0.6	<5 [1]
pH		7.5	7.9	6.8	6.6	
NH_4^+-N	mg/kg	23.41	8.8	5.06	184.48	
NO_3^--N	mg/kg	7.69	17.13	37.39	7.1	
NO_2^--N	mg/kg	nd	nd	nd	nd	
CEC	cmol+/kg	55.6	84.9	33.1	62.8	
total N	%	0.73	0.95	0.68	2.23	0.6 [2]
total P	%	0.09	0.12	0.17	0.42	0.25 [2]
total Ca	%	7.88	5.08	4.15	3.80	3 [2]
total Na	%	0.06	0.07	0.11	0.05	
total C	%	18.4	22.2	17	29.1	
inorganic C	%	5.07	1.65	0.89	1.51	
organic C	%	13.33	20.55	16.11	27.59	
C:N		18	24	19	34	22 [1]
total Zn	mg/kg	95	121	437	94	500 [3]
total Cu	mg/kg	20	25	58	25	60 [3]
total Ni	mg/kg	62	58	25	41	60 [3]
total Cd	mg/kg	3.6	0.5	1.9	1.8	3 [3]
total Cr	mg/kg	91.5	94.1	33.4	76.9	50 [3]
total Co	mg/kg	9.2	6.3	11.6	7.2	25 [3]
total Pb	mg/kg	73	35	35	26	150 [3]
total As	mg/kg	1.49	1.87	4.23	1.68	10 [3]
total Se	mg/kg	0.08	0.17	1.12	0.23	2 [3]

[1] typical
[2] typical minimum
[3] maximum; based on upper limit of normal concentrations in soil

A.2 Analysis of Elutriates prepared from compost sources (Report section 2.3)

Parameter	Units	Compost				Recommended Maximum Concentrations of Trace Elements in Irrigation Waters[1] (unless otherwise stated)	
		Gu	Lc	Sc	He	For waters used continuously on all soil	For use up to 20 years on fine textured soils of pH 6.0 to 8.5
Mn	Fg/mL	0.01	0.22	1.61	2.45	0.2	10
Cu	Fg/mL	0.02	0.05	0.06	1.13	0.2	5
Zn	Fg/mL	<0.01	0.05	0.18	1.85	2.0	10
Ni	Fg/mL	<0.05	<0.05	<0.05	0.29	0.2	2
Co	Fg/mL	<0.1	<0.1	<0.1	<0.1	0.050	5
Cd	Fg/mL	<0.05	<0.05	<0.05	<0.05	0.010	0.050
Cr	Fg/mL	<0.1	<0.1	<0.1	0.2	0.10	1
Pb	Fg/mL	<0.1	<0.1	<0.1	0.1	5	10
NO_2	Fg/mL	<0.01	<0.01	<0.01	<0.01	10 mg/L $N0_2$ and 100 mg/L $N0_2$ + $N0_3$ for Livestock Watering	
NO_3	Fg/mL	<0.01	<0.01	4.9	<0.01		
NH_4	Fg/mL	2.52	0.67	0.08	171.7		
pH		7.82	8.03	7.52	7.14	4.5-9.0	
EC	mS/cm	1.42	1.98	4.27	7.9	<1	
total coliforms	colonies/ 100 mL	<100	<100	<100	O/G	1000 for swimming water	
E. coli	**colonies/ 100 mL**	**<10**	**<10**	**<10**	**<10**	**100 for swimming water**	

[1] Source: Ontario Ministry of the Environment. 1984. Water Management. Goals, policies, objectives and implementation procedures of the Ministry of the Environment. November 1978, Revised May 1984.

A.3 Lettuce seed germination in compost-sand mixes, %, (Section 2.2). Results of Linear Regression for Gu, Sc, and Lc Compost Materials

Compost Material	a (Y intercept)	b (slope)	R^2	P
Gu	84.3	-36.65	0.177	0.0820
Sc	84.8	-37.97	0.269	0.0275
Lc	80.9	-31.19	0.134	0.1356

A.4 Density and Moisture Content of Compost Materials used in studying effects of compost type and rate on corn emergence (Section 2.4)

Compost Source	Density (g dry/cm^3)	Moisture Fraction (g moisture/ g wet compost)
Gu	0.438 a	0.448 b
Sc	0.422 a	0.426 b
Lc	0.264 c	0.557 a
He	0.360 b	0.342 c

A.5 Application Rates of Compost Materials used in studying effects of compost type and rate on corn emergence (Section 2.4)

Compost Source	Application Rate in Dry Mg ha^{-1} (wet weight equivalent)			
	Depth of Application, cm (inches)			
	1.3 (0.5)	2.5 (1.0)	3.8 (1.5)	6.4 (2.5)
Gu	64 (116)	104 (189)	161 (292)	264 (479)
Sc	61 (106)	104 (181)	155 (270)	251 (438)
Lc	39 (88)	66 (149)	92 (208)	159 (360)
He	54 (82)	86 (131)	131 (199)	211 (321)

A.6 Effects of compost application rate on emergence of corn (Section 2.4). Analysis of Variance: Probability Levels

Source	df	Study variable				
		E5*	E6	E7	E8	Plant Weight
compost	3	<0.001	0.005	0.872	0.969	<0.001
depth	4	<0.001	<0.001	0.016	0.114	0.018
depth x compost	12	0.127	0.589	0.759	0.722	0.895
error	40 (20 for E5)					

*E5, etc. = seed emergence at days after planting

A.7 Compost Depths and Application Rates used in studying effects of compost rate on soybean emergence (Section 2.5)

Depth of Application in cm	1.3	2.5	3.8	6.4
Application Rate in Dry Mg ha^{-1} (wet weight equivalent)	39 (68)	72 (125)	104 (181)	181 (314)

APPENDIX B

Appendix to Section 3

B.1 **Analysis of Sc Compost Material Used in Rate and Time of Compost Application Field Studies**
B.2 **Compost Application Rates for the Corn Rate Trial**
B.3 **Nitrogen Response**
B.4 **Compost Application Rates in the Soybean Rate Trial**
B.5 **Weeds emerged in the soybean rate study measured June 15, 1995, 20 days after planting**

B.1 Analysis of Sc Compost Material Used in Rate and Time of Compost Application Field Studies (Section 3)

Parameter	units, dry wt basis	Fall applications		Spring applications		MOEE Compost Guidelines
		Mean	SD	Mean	SD	
EC (total salts), sat'd	mS/cm	10.3	0.82	5.7	1.97	<3.5 [1]
SAR		16.1	1.68	10.8	3.45	<5 [1]
pH		7.5	0.08	7.6	0.08	
total N	%	2.1	0.22	1.5	0.13	0.6 [2]
total P	%	0.40	0.06	0.30	0.15	0.25 [2]
total K	%	1.2	0.05	0.80	0.12	3 [2]
total C	%	35	2.3	33.4	1.8	
inorganic C	%	.7	0.16	0.9	0.34	
organic C	%	34.3	2.3	32.5	2.1	
C:N		16.3	1.8	22.3	1.6	22 [1]
total Zn	mg/kg	345	56	376	28	500 [3]
total Cu	mg/kg	108	10.5	113	5.0	60 [3]
total Mn	mg/kg	618	51	769	50	
total Ni	mg/kg	21	3.6	23	11.3	60 [3]
total Cd	mg/kg	1	0.12	1.1	0.14	3 [3]
total Cr	mg/kg	49	16	65	9	50 [3]
total Co	mg/kg	12.4	0.81	14.4	0.4	25 [3]
total Pb	mg/kg	35	17	20	15	150 [3]
total As	mg/kg	13	2.3	15	2.4	10 [3]
total Se	mg/kg	1.1	0.23	1.2	0.08	2 [3]

[1] typical
[2] typical minimum
[3] maximum; based on upper limit of normal concentrations in soil

B.2 Compost Application Rates (Mg ha^{-1}) for the Corn Rate Trial (Section 3)

Target Application Rate	Time				Overall mean ±s.e.m.	
	Fall		Spring			
	Wet	Dry	Wet	Dry	Wet	Dry
100	90	49	101	42	95 ±3.0	45 ±1.6
150	131	69	165	69	148 ±7.5	69 ±2.2
300	277	149	299	129	288 ±6.4	139 ±4.6

B.3 Nitrogen Response

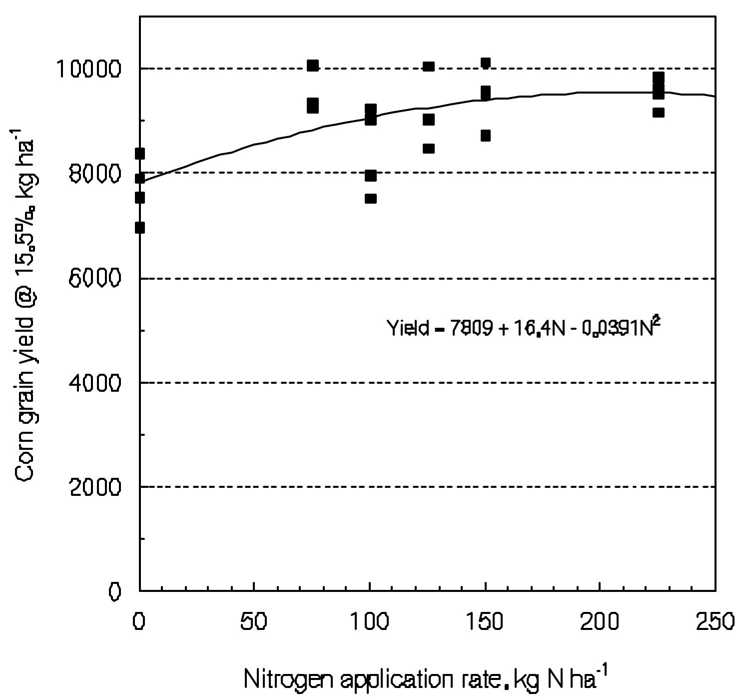


Figure 32 Nitrogen response for corn, compost application rate study, 1995.

B.4 Compost Application Rates (Mg ha^{-1}) in the Soybean Rate Trial (Section 3)

Target Application Rate	Time				Overall mean, ±s.e.m.	
	Fall		Spring			
	Wet	Dry	Wet	Dry	Wet	Dry
100	91	50	95	40	93 ±2.9	45 ±2.1
150	146	77	157	67	152 ±5.1	72 ±2.4
300	301	160	299	133	300 ±7.8	146 ±6.0

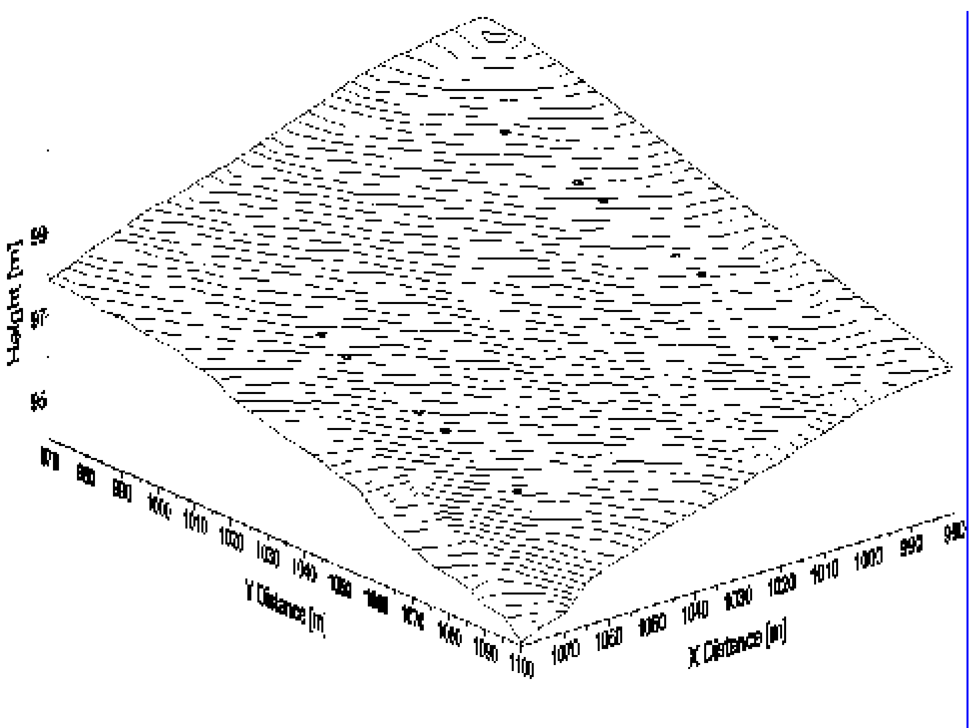
B.5 Weeds emerged (plants m^{-2}) in the soybean rate study measured June 15, 1995, 20 days after planting (Section 3)

		No compost	300 Mg ha^{-1} compost application rate
Annual Broadleaved common yellow wood sorrel; annual smartweed; lamb's-quarters; ragweed; stinkweed	range	0-37	0-3
	average	16	1
Annual Grass	range	0-1	0
	average	0	0
Perennial dandelion; field bindweed; milkweed; mouse-eared chickweed; plantain; Canada thistle	range	8-51	1-19
	average	27	7
Other, not identified	range	0-60	0
	average	8	0
Total	range	19-119	1-19
	average	51	8

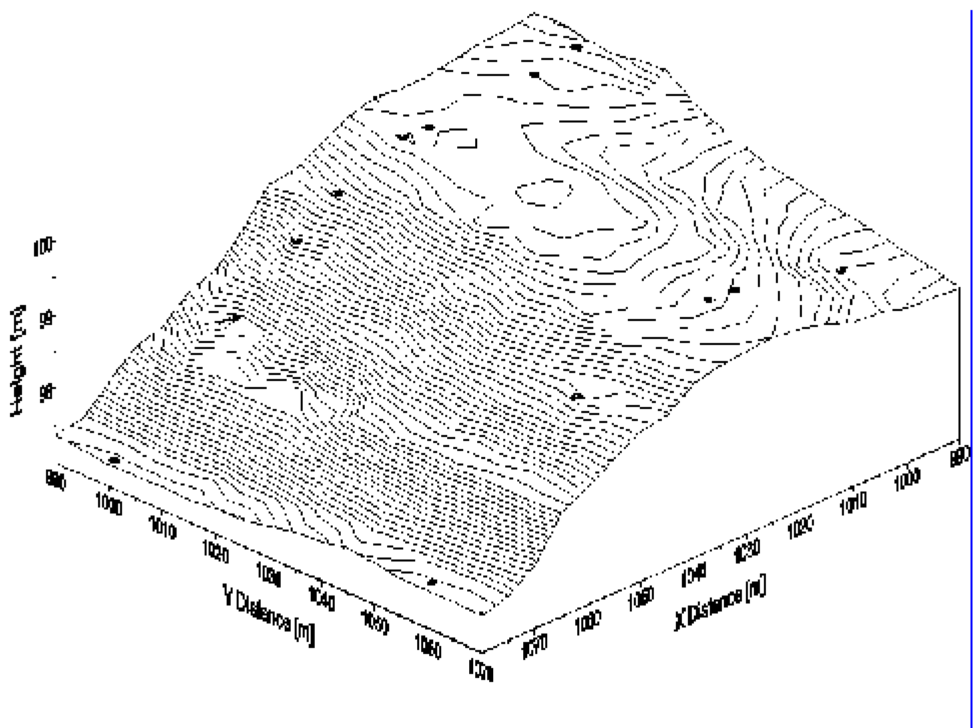
APPENDIX C

Appendix to Section 5

C.1 Location of Research Sites



C.2 Elevation at Research Sites



Loam Site

Clay Loam Site

C.3 Baseline Site Characterization

Table C.1 Analysis of Inorganic Elements (mg kg^{-1}) in Soils with Depth (cm)

Element	Loam			Clay loam			MOEE upper limit normal[1]	Mean natural background levels of metals in agricultural soils of Ontario[2,3]
	0-20	20-40	40-60	0-20	20-40	40-60		
Co	7.3	8.0	9.3	12.3	16.3	13.7	25	4.4
Cd	1.0	1.0	1.7	1.3	1.7	2.3	3	0.56
Cr	5.7	6.3	4.0	16.3	24.0	16.0	50	14.3
Pb	16.7	17.3	20.3	22.7	24.0	25.3	150	14.1
Zn	56	49.7	40.3	63.7	70.7	53.7	500	53.5
Cu	9.3	15.0	13.7	18.3	24.7	16.3	60	25.4
Ni	7.7	8.3	9.0	12.3	17.3	15.7	60	15.9
As	3.9	4.4	4.8	1.6	1.8	1.8	10	6.3
Se	.387	.377	.293	.397	.250	.197	2	not measured

[1] Source: Waste Reduction Office, Ontario Ministry of the Environment. 1991. Interim Guidelines for the Production and Use of Aerobic Compost in Ontario. Queen's Printer for Ontario. pp. 7-8.

[2] Source: Frank, R., K. Ishida and P. Suda. 1976. Metals in agricultural soils of Ontario. Can. J. Soil Sci. 56:181-196.

[3] Based on 296 farm fields sampled to 15 cm soil depth

Note: sampling: one composite soil sample per block at each soil depth

Table C.2 Carbon and Nitrogen Analysis

Site	Soil depth cm	Total C %	Organic C %	Total N %	C:N ratio
Loam	0-20	2.0	1.9	0.206	9.3
	20-40	2.0	1.1	0.135	8.1
	40-60	3.2	0.8	0.069	12.2
Clay loam	0-20	1.7	1.5	0.182	8.4
	20-40	1.8	1.0	0.135	7.4
	40-60	3.9	1.1	0.100	10.4

Note: sampling: one composite soil sample per block at each soil depth

Table C.3 Topsoil properties and fertility levels

Parameter	units	Loam	Clay loam
Soil test P_2O_5	mg/L (rating)	21 (H)	14 (M)
	recommendation kg ha^{-1}	20	20
Soil test K_2O	mg/L (rating)	63 (M)	86 (M)
	recommendation, kg ha^{-1}	80	50
Soil test Mg	mg/L	219	99
pH		7.6	7.8
CEC (Rhoades, 1982)	cmol/kg	16.8	19.3
soil texture (Canadian Soil Survey Committee, 1979)	sand, % silt, % clay, % texture:	40 47.6 12.3 loam	34.1 43 22.9 loam
organic matter	%	3.3	3.2
K_{sat} (Reynolds, 1993)	cm/h, rating	5.04, moderate	3.82, moderate
bulk density	g/cm^3	1.50	1.46
soil moisture (Topp *et al.*, 1993)	g/100g @ saturation @ 333 mbar	29.37 18.18	31.61 20.66
water stable aggregates (Pojasok and Kay, 1990)	%	22.15	16.58

Note: sampling: single composite samples (0-15 cm) per site (fertility, CEC, psa);
one composite sample (0-15 cm) per block (water stable aggregates);
two soil cores per block (near soil surface) (hydraulic conductivity, bulk density and moisture retention)

C.4 Agronomic practices used in main trial

Practice	loam site	clay loam site
previous crop (1993)	soybeans	winter wheat
fall (1993) tillage	none	chisel plow
spring (1994) tillage	single pass with S-tine cultivator to incorporate compost	single pass with cultivator with rolling harrows to incorporate compost; single pass with packer after planting
planting 1994	May 30, Pioneer variety	May 23, Pioneer 3902
fertilizer 1994	1) preplant: 67 kg K_20 ha^{-1} bulk spread; 2) at planting: 78 kg N ha^{-1} (70 lbs N ac^{-1}) as UAN (28%) spray application; 56 kg ha^{-1} 10-34-0; 3) after planting: 45 kg N ha^{-1} as urea broadcast [Total application: 129 kg N ha^{-1}; 19 kg P_20_5 ha^{-1}; 67 kg K_20 ha^{-1}]	1) preplant: 129 kg ha^{-1} 18-32-16 bulk spread 2) at planting: 56 L ha^{-1} 6-24-6; 314 L ha^{-1} of UAN sprayed [Total application: 115 kg N ha^{-1}; 55 kg P_20_5 ha^{-1}; 24 kg K_20 ha^{-1}]
weed control 1994	tank mix 2.4 L ha^{-1} atrazine and 1 L ha^{-1} Pardner (June 16); tank mix 0.75 Banvel and 0.1 kg ha^{-1} Ultim (June 28)	tank mix 0.1 kg ha^{-1} Ultim and 0.5 L ha^{-1} Pardner (June 16)
harvest 1994	October 17, 18	October 18, 20
fall (1994) tillage	none	none
spring (1995) tillage	single pass with disc to incorporate compost	2 passes with disc to incorporate compost
planting 1995	May 20; Pioneer 3921	May 20; Pioneer 3921
fertilizer 1995	1. at planting: 4 US gal ac^{-1} 10-34-0 2. after planting (May 26): 80 kg K_2O ha^{-1} as 0-0-60; 127 kg N ha^{-1} as NH_4NO_3 broadcast with Val Mar [Total application: 131 kg N ha^{-1}; 13 kg P_20_5 ha^{-1}; 80 kg K_20 ha^{-1}]	1. at planting: 4 US gal ac^{-1} 10-34-0 2. after planting (May 26): 50 kg K_2O ha^{-1} as 0-0-60; 146 kg N ha^{-1} as NH_4NO_3 broadcast with Val Mar [Total application: 150 kg N ha^{-1}; 13 kg P_20_5 ha^{-1}; 50 kg K_20 ha^{-1}]
weed control 1995	Primextra Light & Banvel	Ultim & Pardner (June 15)
harvest 1995	October 20, 24, 25	October 23, 24
fall (1995) tillage	none	none
spring (1996) tillage	single pass with disc to incorporate compost	2 passes with disc to incorporate compost
planting 1996	June 3; Funk 4030	June 2; Asgrow 1923 soybeans
fertilizer 1996	1. 4 US gal ac^{-1} 10-34-0 at planting 2. after planting (June 28): 80 kg K_2O ha^{-1} as 0-0-60; 127 kg N ha^{-1} as NH_4NO_3 broadcast with Val Mar [Total application: 131 kg N ha^{-1}; 13 kg P_20_5 ha^{-1}; 80 kg K_20 ha^{-1}]	4 US gal ac^{-1} 6-24-6 [Total application: 2.3 kg N ha^{-1}; 9.2 kg P_20_5 ha^{-1}; 2.3 kg K_20 ha^{-1}]
weed control 1996	Ultim & Pardner & atrazine directed postemerge (Aug. 2)	Pursuit & Roundup preplant (June 1); Assure postemerge (June 26)
harvest 1996	November 11, 12	October 17

Note:

Herbicide Brand/Trade name - common name
Assure - quizalofop-ethyl
Banvel - dicamba
Pardner - bromoxynil
Primextra Light - metolachlor/atrazine
Pursuit - imazethapyr
Roundup - glyphosate
Ultim - nicosulfuron/rimsulfuron

C.5 Compost Application Rates Achieved in Main Trial

Year	Source	Site	Moisture Content, % (moisture/wet weight)	Wet Rate, Mg ha^{-1}	Dry Rate, Mg ha^{-1}
1994	Sc	loam	55	99	45
		clay loam	53	111	52
		mean	54	105±2.5	48±1.3
	Lc	loam	56	100	44
		clay loam	56	112	49
		mean	56	106±3.1	47±1.6
1995	Sc	loam	47	102	54
		clay loam	47	106	56
		mean	47	104±0.93	55±0.52
	Lc	loam	55	135	61
		clay loam	55	142	64
		mean	55	138±1.7	63±0.78
1996	Sc	loam	55	115	52
		clay loam	56	113	50
		mean	55	114±0.83	51±0.45
	Lc	loam	51	120	58
		clay loam	53	124	59
		mean	52	122±0.43	59±0.43

C.6 Average Compost Analysis Applied at Sites for 1994, 1995, and 1996

Sampling Parameter, units	Lc Compost			Sc Compost			MOEE Guidelines (OMOE, 1991)
	1994	1995	1996	1994	1995	1996	
pH	8.2	7.6	7.6	8.0	7.6	8.3	5.5 - 8.5 [3]
Total N, %	1.05	0.94	1.19	1.24	0.99	1.54	0.6 [1]
Total P, %	0.17	0.15	0.17	0.29	0.21	0.23	0.25 [1]
Total K, %	0.98	0.37	0.45	2.5	0.79	1.22	0.20 [1]
SAR	1.5	0.4	1.3	4.3	8.9	9.5	<5 [3]
EC, mS cm^{-1} (1994 from sat'd paste; 1995 and 1996 from 2:1 water:compost)	0.4	4.5	0.6	0.5	9.7	1.7	<3.5 [3]
Organic C, %	24	19	21	30	27	25	
Total Zn, mg kg^{-1}	117	115	61	384	455	177	500 [2]
Total Cu, mg kg^{-1}	26	26	33	86	132	52	60 [2]
Total Mn, mg kg^{-1}	252	274	n.m.	495	663	n.m.	
Total Ni, mg kg^{-1}	56	8	18	42	13	17	60 [2]
Total Cd, mg kg^{-1}	5.5	<2	<1	5	<2	<1	3 [2]
Total Cr, mg kg^{-1}	84	7	16	68	17	24	50 [2]
Total Co, mg kg^{-1}	8	5	8	14	14	9	25 [2]
Total Pb, mg kg^{-1}	38	30	16	40	37	35	150 [2]
Total As, mg kg^{-1}	nm	nm	2.5	nm	nm	2.4	10 [2]
Total Se, mg kg^{-1}	nm	nm	<0.5	nm	nm	<0.5	2 [2]
Total Hg, mg kg^{-1}	nm	nm	.04	nm	nm	0.07	0.15 [2]
Total Mo, mg kg^{-1}	nm	nm	<2.5	nm	nm	<2.5	2 [2]

1. typical minimum for good compost quality
2. maximum concentration
3. typical of good compost quality

nm not measured

C.7 Nitrogen Response Curves

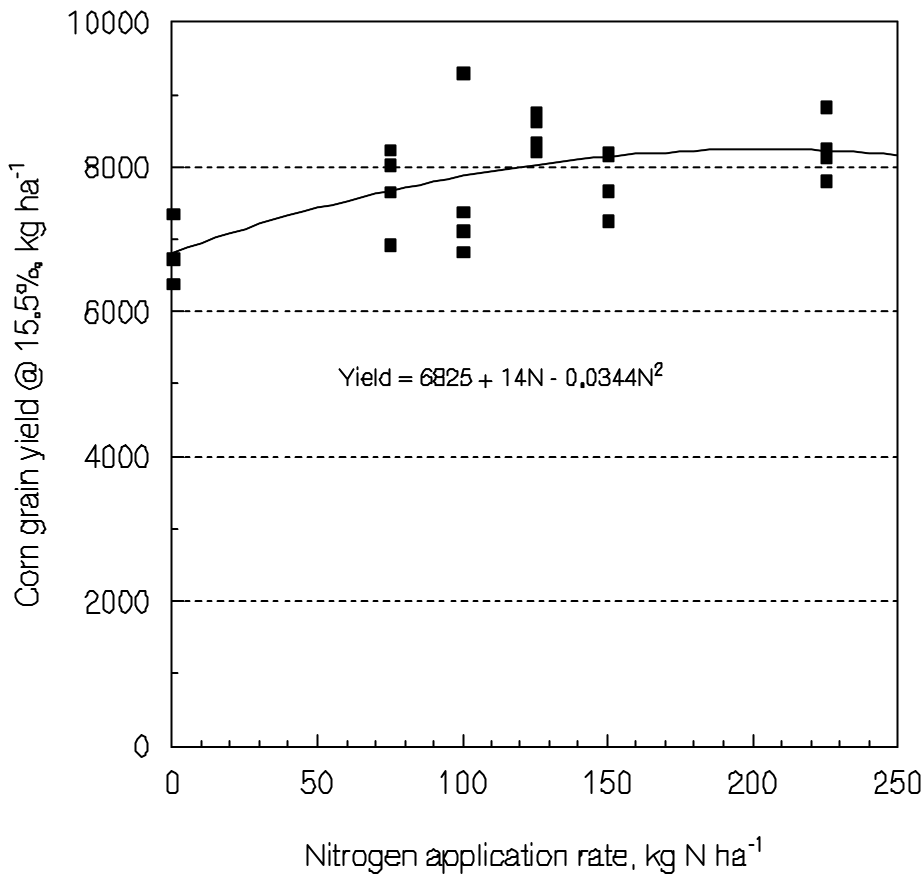


Figure 1 Nitrogen response for corn at loam site, 1994

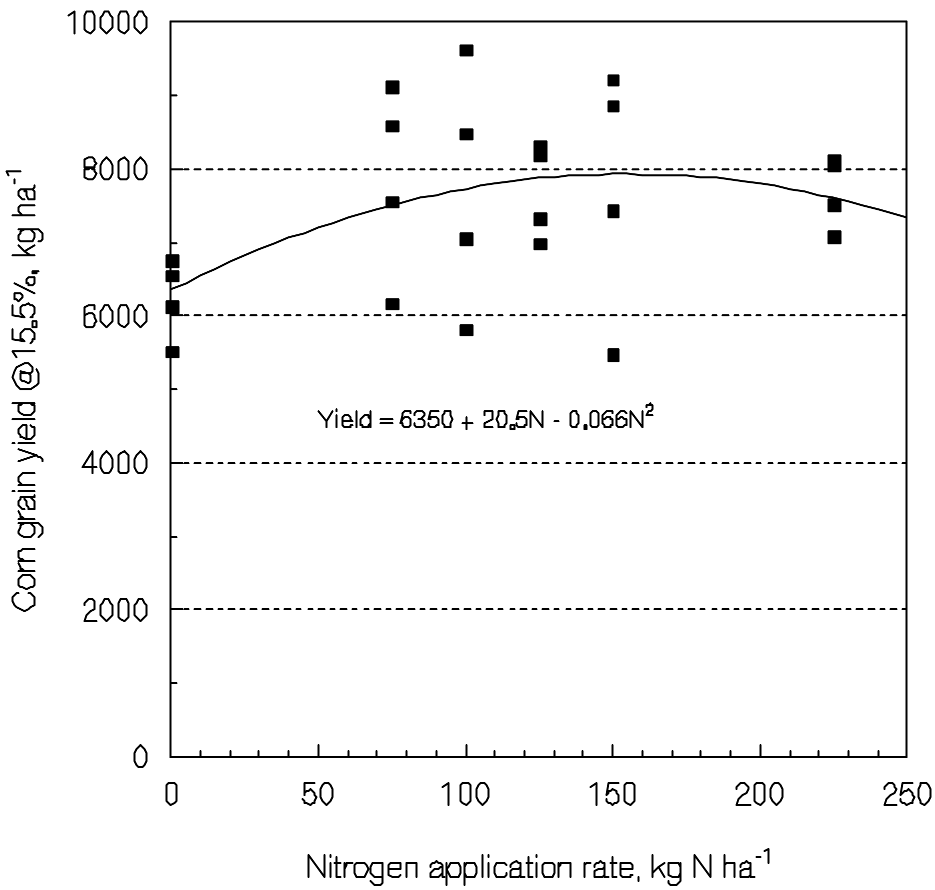


Figure 2 Nitrogen response for corn at loam site, 1995

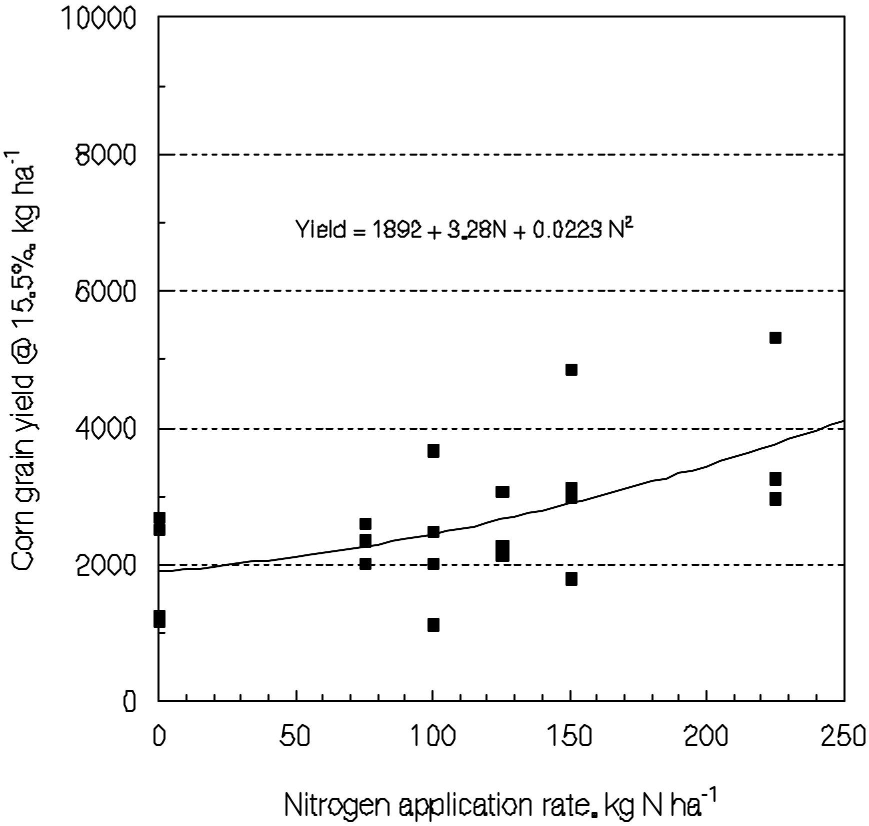


Figure 3 Nitrogen response for corn at loam site, 1996.

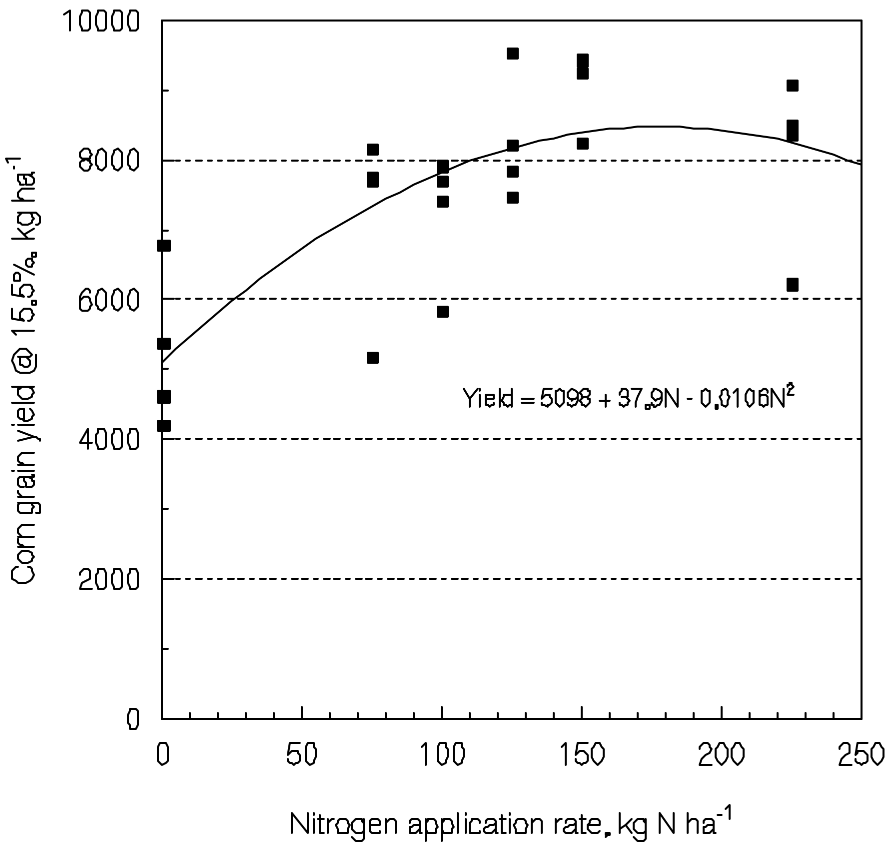


Figure 4 Nitrogen response for corn at clay loam site, 1994.

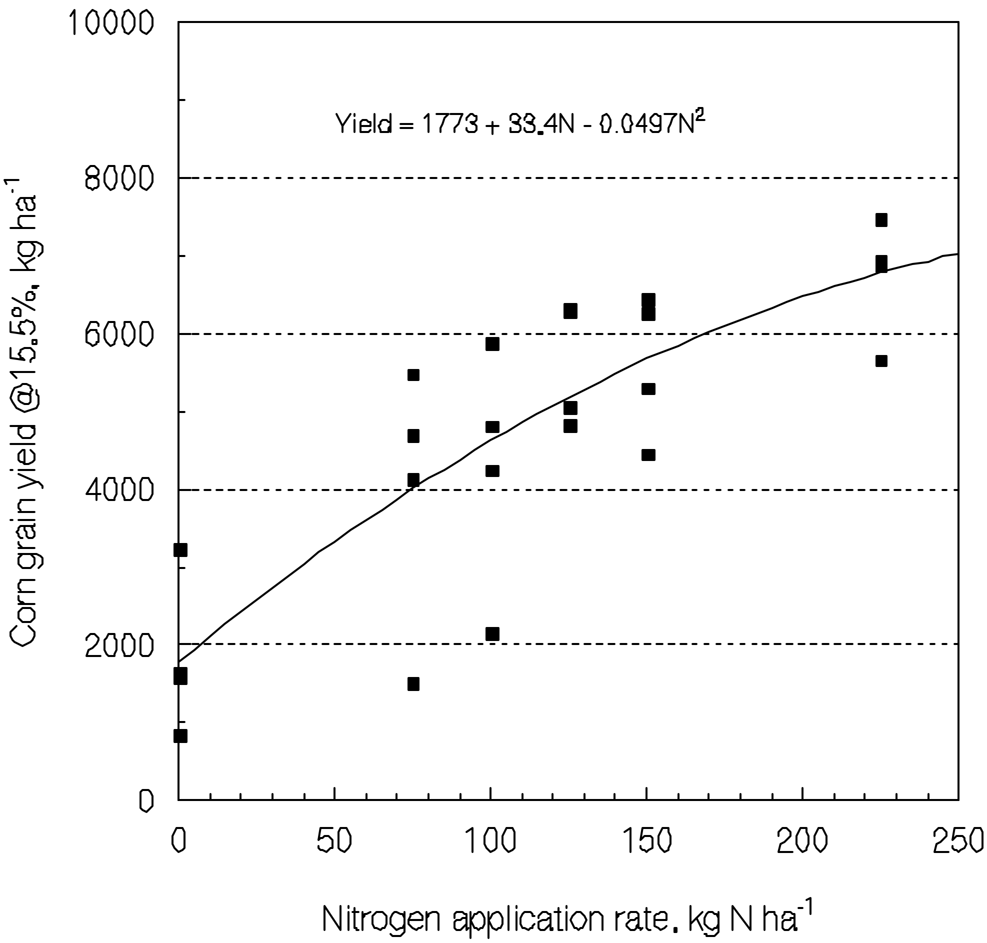


Figure 5 Nitrogen response for corn at clay loam site, 1995.

C.8 Monthly total rainfall and potential evapotranspiration

Year	Month	Rainfall.	Potential	Rainfall -
Loam site				
1994	June (146)	43.5	67	
	July	37.5	119	
	August	100.0	102	
	September	39.0	64	
		220	352	-132
1995	June	38.5	133	
	July	43.6	152	
	August	108.6	120	
	September	46.6	93	
		237.3	498	-260.7
1996	June	119.2	(76 from clay loam site)	
	July	121.4	133	
	August	38.6	131	
	September	178.6	100	
		457.8	440	17.8
Clay loam site				
1994	June (146)	49.8	76	
	July	37	134	
	August	54.5	107	
	September	27	69	
		168.3	386	-217.7
1995	June	25.7	134	
	July	78	150	
	August	107.2	124	
	September	55	92	
		265.9	500	-234.1
1996	June	95	76	
	July	114.4	116	
	August	40.8	133	
	September	171.1	90	
		421.3	415	6.3

C.9 Emergence (plants m^{-2}) and Silking date (days after planting) for loam site

Compost source	Tillage	First Year of application	1994			1995			1996		
			emerg. 16 DAP	emerg. 23 DAP	silking, DAP	emerg. 13 DAP	emerg. 20 DAP	silking, DAP	emerg. 16 DAP	emerg. 22 DAP	silking, DAP
Control			5.9	6.6	68	5.9	7.5	68	6.3	6.4	76
Sc	incorporated	1994	6.5	6.5	65	6.0	7.8	67	7.3	7.3	74
	surface	1994	5.9	6.4	65	5.9	7.6	67	5.6	6.1	77
Lc	incorporated	1994	6.3	6.8	66	4.9	7.2	67	5.8	6.2	74
	surface	1994	6.4	6.7	65	5.9	7.4	67	6.9	7.2	76
Sc	incorporated	1995				5.9	7.3	67	7.2	7.3	74
	surface	1995				5.8	7.2	67	6.9	7.0	77
Lc	incorporated	1995				6.0	7.6	67	6.3	6.5	72
	surface	1995				6.0	7.7	67	6.4	6.6	76
Sc	incorporated	1996							5.6	5.7	77
	surface	1996							6.2	6.2	74
Lc	incorporated	1996							6.6	6.8	72
	surface	1996							6.7	7.0	75
ANOVA P:		Control	.215	1.0	.005	.889	.977	.077	.643	.494	.494
		Compost	.564	.290	.804	.546	.865	.769	.978	.562	.030
		Tillage	.491	.628	.464	.609	.932	.769	.978	.783	.002
		Year				.487	.865	.769	.219	.144	.694
		Compost x Tillage	.263	.903	.236	.381	.500	.384	.034	.038	.102
		Compost x Year				.334	.047	.384	.024	.008	.618
		Tillage x Year				.487	1.0	.384	.442	.506	.056
		Compost x Tillage x Year				.546	.799	.769	.008	.026	.042

C.10 Emergence (plants m^{-2}), Silking date (days after planting), and soybean nodule mass (g pl^{-1} x 10^{-3}) for clay loam site

Compost source	Tillage	First Year of application	1994			1995			1996 (soybeans)		
			emerg. 16 DAP	emerg. 23 DAP	silking, DAP	emerg. 13 DAP	emerg. 20 DAP	silking, DAP	emerg. 14 DAP	emerg. 22 DAP	nodule mass
Control			5.3	5.7	66	5.5	7.4	67	46	50	345
Sc	incorporated	1994	4.5	4.8	70	6.2	7.2	68	45	49	395
	surface	1994	6.0	6.2	72	6.0	7.2	71	41	52	517
Lc	incorporated	1994	5.1	5.7	70	6.2	7.2	66	45	53	548
	surface	1994	6.3	6.5	68	6.7	7.6	67	48	51	413
Sc	incorporated	1995				5.0	7.0	68	44	49	437
	surface	1995				6.6	7.4	67	48	51	449
Lc	incorporated	1995				6.6	7.8	67	46	50	463
	surface	1995				6.5	7.3	69	44	48	443
Sc	incorporated	1996							44	51	453
	surface	1996							46	48	464
Lc	incorporated	1996							48	53	506
	surface	1996							44	49	504
ANOVA P:		Control	.708	.666	.010	.098	.619	.230	.896	.905	.004
		Compost	.195	.050	.130	.060	.081	.030	.467	.683	.224
		Tillage	.002	.005	.882	.130	.474	.004	.898	.514	.922
		Year				.673	.544	.506	.947	.662	.449
		Compost x Tillage	.602	.345	.204	.371	.410	1.0	.537	.302	.027
		Compost x Year				.548	.544	.004	.608	.751	.786
		Tillage x Year				.312	.474	.323	.864	.523	.976
		Compost x Tillage x Year				.053	.053	.007	.197	.857	.051

C.11 Leaf nitrogen content (%), and Corn grain yield (kg ha^{-1} @ 15.5%) for loam site

Compost source	Tillage	First Year of application	1994	1995			1996		
			Yield	Leaf N	Yield (+N)	Yield (-N)	Leaf N	Yield (+N)	Yield (-N)
Control			6908	3.2	8659	6884	2.6	3861	2231
Sc	incorporated	1994	8266	3.0	9353	6626	2.5	4574	3235
	surface	1994	7593	3.0	9058	6583	2.4	3456	1985
Lc	incorporated	1994	8145	3.1	9207	7740	2.7	4513	2926
	surface	1994	7829	3.1	9750	7922	2.2	3854	2431
Sc	incorporated	1995		3.2	9333	6914	2.5	3909	2248
	surface	1995		3.1	9114	7008	2.2	3368	2213
Lc	incorporated	1995		3.2	9388	7939	2.4	4721	2401
	surface	1995		3.1	9862	8189	2.4	4188	2361
Sc	incorporated	1996					2.6	3179	2370
	surface	1996					2.3	3809	2085
Lc	incorporated	1996					2.6	4562	2412
	surface	1996					2.0	3667	2520
ANOVA P:		Control	.023	.168	.012	.210	.271	.603	.422
		Compost	.883	.273	.074	<.000	.702	.001	.323
		Tillage	.212	.478	.498	.630	.002	.002	.033
		Year		.199	.657	.248	.704	.161	.120
		Compost x Tillage	.646	.637	.043	.704	.480	.168	.215
		Compost x Year		.791	.730	.805	.550	.124	.857
		Tillage x Year		.471	.992	.838	.234	.215	.058
		Compost x Tillage x Year		.784	.846	.944	.212	.038	.608

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C.12 Corn leaf nitrogen content (%), Corn grain yield (kg ha^{-1} @ 15.5% moisture), Soybean yield (kg ha^{-1} @ 14% moisture) and Soybean Grain N content for clay loam site

Compost source	Tillage	First Year of application	1994	1995			1996	
			Yield	Leaf N	Yield (+N)	Yield (-N)	Soybean Yield	Grain N
Control			7320	2.5	5930	2513	3219	6.37
Sc	incorporated	1994	5274	2.2	5576	2903	2997	6.20
	surface	1994	4521	1.9	3607	2596	3591	6.23
Lc	incorporated	1994	6058	2.4	5829	2935	3253	6.15
	surface	1994	7032	2.3	6257	2659	3249	6.38
Sc	incorporated	1995		2.3	5922	2829	3030	6.34
	surface	1995		2.3	5213	2556	3186	6.27
Lc	incorporated	1995		2.4	6292	4058	3144	6.36
	surface	1995		2.1	4883	2982	3261	6.27
Sc	incorporated	1996					3158	6.16
	surface	1996					3009	6.06
Lc	incorporated	1996					3176	6.25
	surface	1996					2972	6.13
ANOVA P:		Control	.020	.027	.133	.495	.700	.192
		Compost	.008	.133	.001	.299	.846	.409
		Tillage	.849	.005	<.000	.254	.247	.711
		Year		.321	.222	.426	.105	.097
		Compost x Tillage	.144	.927	.050	.643	.120	.640
		Compost x Year		.030	.001	.354	.720	.903
		Tillage x Year		.988	.496	.645	.038	.205
		Compost x Tillage x Year		.076	.001	.617	.213	.660

C.13 Ammonium and nitrate nitrogen levels (mg N L^{-1}) in soil solution at loam site

Compost source	Tillage	First Year of application	1994 30 cm NH_4	1994 30 cm NO_3	1994 80 cm NH_4	1994 80 cm NO_3	1995 30 cm NH_4	1995 30 cm NO_3	1995 80 cm NH_4	1995 80 cm NO_3	1996 30 cm NH_4	1996 30 cm NO_3
Control			.263	16.3	.203	22.3	.336	7.2	.840	6.9	.147	8.0
Sc	incorporated	1994	.867	13.3	.350	12.5	.587	10.0	.617	7.5	.523	12.4
	surface	1994	.593	9.4	.180	8.9	.377	7.6	.443	6.6	.333	5.8
Lc	incorporated	1994	.447	11.7	.123	11.9	.447	7.9	.437	3.3	.193	8.3
	surface	1994	.540	13.0	.313	11.5	.483	6.4	.637	6.4	.337	6.9
Sc	incorporated	1995					.640	10.0	.503	9.1	.203	12.6
	surface	1995					.550	6.6	.427	6.1	.260	7.2
Lc	incorporated	1995					.843	4.8	.443	7.3	.190	11.2
	surface	1995					.460	7.3	.367	6.5	.213	6.6
Sc	incorporated	1996									.203	6.4
	surface	1996									.303	7.8
Lc	incorporated	1996									.163	9.6
	surface	1996									.200	7.2
ANOVA P:		Control	.060	.023	.323	.008	.055	.706	.948	.746	.342	.768
		Compost	.213	.589	.178	.485	.857	.081	.710	.104	.187	.715
		Tillage	.695	.357	.558	.879	.155	.273	.700	.656	.667	.004
		Year					.186	.448	.456	.161	.193	.395
		Compost x Tillage	.210	.142	.011	.964	.916	.121	.474	.092	.550	.724
		Compost x Year					.742	.784	.815	.394	.697	.497
		Tillage x Year					.502	.461	.669	.100	.842	.179
		Compost x Tillage x Year					.232	.244	.477	.604	.397	.192

C.14 Ammonium and nitrate nitrogen levels (mg N L^{-1}) in soil solution at clay loam site

Compost source	Tillage	First Year of application	1994				1995				1996	
			30 cm		80 cm		30 cm		80 cm		30 cm	
			NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
Control			.310	11.4	.163	6.0	.290	3.6	.422	4.6	.253	9.5
Sc	incorporated	1994	.540	7.8	.300	3.8	.540	3.4	.420	3.1	.333	7.4
	surface	1994	.503	5.5	.080	2.2	.720	3.4	.370	2.7	1.97	8.6
Lc	incorporated	1994	.427	16.0	.130	5.2	.593	9.2	.413	4.5	.210	7.5
	surface	1994	.213	10.8	.077	5.5	.540	7.5	.527	1.7	.290	6.1
Sc	incorporated	1995					.337	4.8	.323	3.1	.237	8.5
	surface	1995					.663	4.0	.310	2.7	.257	11.4
Lc	incorporated	1995					.437	7.7	.403	3.3	.253	10.7
	surface	1995					.455	4.6	.363	5.8	.260	5.2
Sc	incorporated	1996									.253	9.8
	surface	1996									.227	8.4
Lc	incorporated	1996									.227	6.7
	surface	1996									.257	13.8
ANOVA P:		Control	.358	.920	.872	.139	.003	.336	.906	.089	.772	.818
		Compost	.070	.055	.362	.045	.347	.160	.274	.674	.289	.756
		Tillage	.228	.248	.166	.533	.318	.803	.981	.440	.298	.808
		Year					.199	.947	.246	.082	.310	.650
		Compost x Tillage	.381	.638	.380	.353	.108	.403	.871	.910	.365	.834
		Compost x Year					.791	.343	.829	.315	.312	.806
		Tillage x Year					.238	.946	.786	.196	.357	.688
		Compost x Tillage x Year					.997	.705	.534	.232	.409	.238

C.15 Dissolved Organic Carbon levels (mg C L^{-1}) in soil solution

Compost source	Tillage	First Year of application	Loam site					Clay loam site				
			1994		1995		1996	1994		1995		1996
			30 cm	80 cm	30 cm	80 cm	30 cm	30 cm	80 cm	30 cm	80 cm	30 cm
Control			41.5	21.7	70.8	40.8	9.8	23.9	52.0	94.8	52.7	19.5
Sc	incorporated	1994	62.6	100.0	26.5	15.4	11.2	48.4	36.4	136.4	30.6	19.0
	surface	1994	46.3	23.6	18.7	22.8	12.9	55.7	16.9	27.8	34.9	32.2
Lc	incorporated	1994	49.8	36.8	29.6	20.4	10.0	55.8	17.5	15.3	35.5	11.3
	surface	1994	29.1	19.9	25.0	24.7	15.3	55.1	23.4	46.6	83.4	18.6
Sc	incorporated	1995			21.6	19.6	11.3			129.2	37.2	15.8
	surface	1995			30.6	18.2	11.2			41.4	36.1	17.9
Lc	incorporated	1995			69.2	30.3	18.0			16.7	36.3	15.1
	surface	1995			21.3	23.0	11.9			36.8	35.5	22.5
Sc	incorporated	1996					13.3					25.8
	surface	1996					10.9					16.1
Lc	incorporated	1996					18.9					16.7
	surface	1996					21.5					15.2
ANOVA P:		Control	.774	.003	.013	.006	.364	.204	.094	.009	.015	.779
		Compost	.225	.001	.175	.398	.101	.857	.656	.027	.050	.056
		Tillage	.155	<.001	.240	.907	.944	.860	.624	.960	.074	.231
		Year			.501	.766	.411			.474	.210	.882
		Compost x Tillage	.730	.001	.225	.732	.864	.831	.371	.079	.122	.970
		Compost x Year			.477	.741	.461			.871	.040	.153
		Tillage x Year			.820	.441	.554			.827	.027	.050
		Compost x Tillage x Year			.186	.915	.604			1.0	.142	.578

C.16 Soil microbial biomass C (g C m^{-2}) at loam site

Compost source	Tillage	First Year of application	June 1994	August 1994	October 1994	June 1995	August 1995	June 1996	August 1996
Control			118	123	124	150	96	117	36
Sc	incorporated	1994	177	97	125	130	93	154	92
	surface	1994	147	145	146	151	120	222	76
Lc	incorporated	1994	118	110	125	146	96	128	50
	surface	1994	141	125	141	161	108	167	133
Sc	incorporated	1995				132	115	187	83
	surface	1995				133	112	163	67
Lc	incorporated	1995				137	101	120	119
	surface	1995				143	102	145	54
Sc	incorporated	1996						101	59
	surface	1996						166	103
Lc	incorporated	1996						108	69
	surface	1996						141	96
ANOVA P:		Control	.414	.819	.427	.562	.389	.239	.218
		Compost	.279	.838	.815	.290	.282	.058	.744
		Tillage	.896	.083	.130	.254	.255	.035	.653
		Year				.266	.645	.136	.959
		Compost x Tillage	.371	.331	.861	.964	.726	.898	.800
		Compost x Year				.788	.626	.608	.984
		Tillage x Year				.438	.206	.318	.248
		Compost x Tillage x Year				.767	.542	.486	.326

C.17 Soil microbial biomass C (g C m^{-2}) at clay loam site

Compost source	Tillage	First Year of application	June 1994	August 1994	October 1994	June 1995	August 1995	June 1996	August 1996
Control			132	144	144	125	96	116	143
Sc	incorporated	1994	136	169	180	141	157	188	237
	surface	1994	138	177	201	103	178	212	261
Lc	incorporated	1994	141	149	167	108	94	164	162
	surface	1994	157	178	162	123	126	152	202
Sc	incorporated	1995				127	140	183	130
	surface	1995				130	133	184	198
Lc	incorporated	1995				99	137	158	121
	surface	1995				112	116	117	207
Sc	incorporated	1996						150	137
	surface	1996						147	75
Lc	incorporated	1996						125	115
	surface	1996						122	159
ANOVA P:		Control	.584	.281	.057	.509	.022	.183	.622
		Compost	.507	.612	.093	.053	.005	.038	.655
		Tillage	.626	.342	.605	.819	.551	.741	.226
		Year				.776	.475	.142	.029
		Compost x Tillage	.691	.600	.368	.042	.965	.453	.396
		Compost x Year				.268	.033	.869	.324
		Tillage x Year				.194	.069	.826	.440
		Compost x Tillage x Year				.152	.551	.867	.740

C.18 Soil Properties in Relation to Annual Compost Additions at the Loam Site

Compost source	Years of application	Soil test Mn (mg L^{-1})	Soil pH	EC (mS cm^{-1})	WSA (%)	Organic C in A horizon (%)	Organic C in A horizon (kg C ha^{-1})
Control		30	7.3	0.12	16.0	1.74	67,340
Sc	3	39	7.3	0.18	14.5	2.39	84,206
Lc		34	7.4	0.17	16.8	2.26	85,899
Sc	2	38	7.4	0.18	14.3	2.01	74,591
Lc		35	7.4	0.16	15.0	2.12	80,482
Sc	1	37	7.3	0.16	17.9	1.94	75,351
Lc		36	7.5	0.15	17.7	1.87	70,016
ANOVA P:	Control	.002	.290	.004	.998	.008	.030
	Compost	.031	.045	.104	.770	.724	.829
	Year	.939	.584	.321	.703	.006	.035
	Compost x Year	.473	.688	.896	.945	.532	.421

C.19 Soil Properties in Relation to Annual Compost Additions at the Clay Loam Site

Compost source	Years of application	Soil test Mn (mg L^{-1})	Soil pH	EC (mS cm^{-1})	WSA (%)	Organic C in A horizon (%)	Organic C in A horizon (kg C ha^{-1})
Control		21	7.5	0.16	12.4	1.73	63,894
Sc	3	24	7.6	0.19	9.4	2.32	71,675
Lc		24	7.6	0.17	14.5	2.27	75,864
Sc	2	27	7.6	0.17	10.4	2.06	70,037
Lc		24	7.7	0.17	11.6	1.96	73,747
Sc	1	21	7.5	0.16	10.5	1.69	51,605
Lc		25	7.6	0.17	9.4	1.76	53,649
ANOVA P:	Control	.259	.332	.477	.180	.070	.790
	Compost	.932	.390	1.00	.040	.996	.429
	Year	.602	.298	.506	.142	.005	.012
	Compost x Year	.424	.952	.292	.017	.764	.932

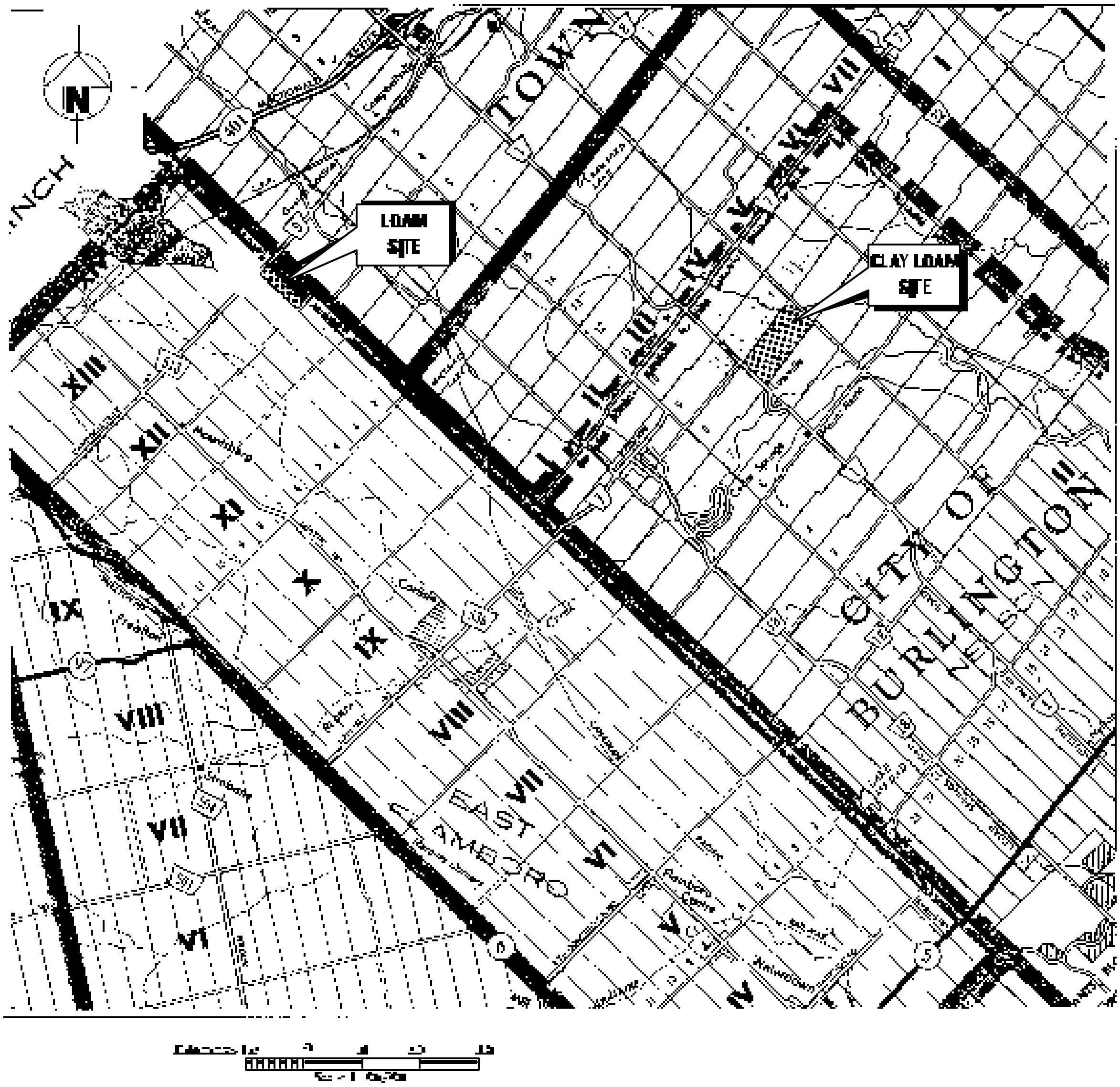
C.20 Surface hydraulic properties from field and soil cores, loam site, individual data points

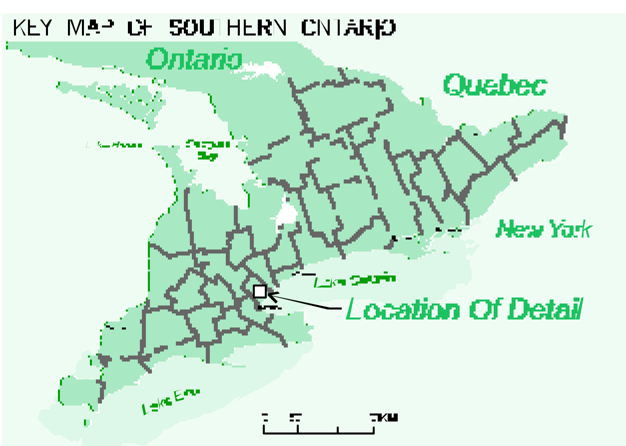
Compost source	Years of application	K_S cm hr^{-1}	K_F cm hr^{-1}	Soil water content, %				Bulk density, g cm^{-3}	Porosity, %			
				h=0 cm	h=10cm	h=333 cm	h=15,000		Macro	Drainable	Available	Residual
Sc	3	12.59	5.43	58.9	51.56	45.89	41.14	1.08	7.34	5.67	4.75	41.14
	3	0.16	11.43	54.60	51.23	41.89	34.39	1.29	3.37	9.34	7.50	34.39
	3	110.51	28.20	50.90	47.12	41.98	39.01	1.28	3.78	5.14	2.97	39.01
Lc	3	1.09	10.32	52.49	44.60	36.10	31.91	1.22	7.89	8.50	4.19	31.91
	3	133.15	16.56	52.37	46.69	40.16	36.29	1.31	5.68	6.53	3.87	36.29
	3	14.00	16.68	53.41	42.78	32.32	27.53	1.25	10.63	10.46	4.79	27.53
Sc	2	134.95	21.39	55.95	48.05	41.21	36.86	1.16	7.90	6.84	4.35	36.86
	2	1.86	21.87	51.79	48.03	38.28	30.31	1.25	3.76	9.75	7.97	30.31
	2	0.24	5.28	48.18	45.09	37.61	29.04	1.42	3.09	7.48	8.57	29.04
Lc	2	1.66	23.19	53.6	48.7	37.42	32.00	1.23	4.90	11.28	5.42	32.00
	2	0.70	3.81	46.91	42.14	36.67	28.57	1.44	4.77	5.47	8.10	28.57
	2	1.68	20.04	47.07	44.72	39.68	31.14	1.37	2.35	5.04	8.54	31.14
Sc	1	3.65	11.13	52.67	46.09	37.72	29.49	1.26	6.58	8.37	8.23	29.49
	1	4.13	26.22	53.3	43.58	33.51	29.00	1.18	9.72	10.07	4.5	29.00
	1	4.28	21.36	52.46	46.14	36.65	30.72	1.26	6.32	9.49	5.93	30.72
Lc	1	0.48	8.4	50.99	44.68	38.86	32.93	1.30	6.31	5.82	5.93	32.93
	1	1.36	22.02	49.98	39.45	34.83	28.01	1.36	10.53	4.62	6.82	28.01
	1	0.60	17.28	50.99	44.68	38.86	32.93	1.30	6.31	5.82	5.93	32.93
Control	0	3.69	5.31	47.29	40.33	33.97	31.63	1.32	6.96	6.36	2.34	31.63
	0	0.10	18.21	45.91	40.98	33.40	28.88	1.39	4.93	7.58	4.52	28.88
	0	1.67	13.56	48.95	43.08	33.96	29.65	1.32	5.87	9.12	4.31	29.65

C.21 Surface hydraulic properties from field and soil cores, clay loam site, individual data points

Compost source	Years of application	K_S cm hr^{-1}	K_F cm hr^{-1}	Soil water content, %				Bulk density, g cm^{-3}	Porosity, %			
				h=0 cm	h=10cm	h=333 cm	h=15,000		Macro	Drainable	Available	Residual
Sc	3	0.01	11.91	51.25	46.67	40.94	36.58	1.33	4.58	5.73	4.36	36.58
	3	1.45	34.32	54.15	47.81	42.63	39.63	1.29	6.34	5.18	3.00	39.63
	3	0.08	30.18	46.54	40.79	36.33	33.00	1.49	5.75	4.46	3.33	33.00
Lc	3	1.58	37.44	53.52	46.31	39.39	34.78	1.36	7.21	6.92	4.61	34.78
	3	20.9	8.13	48.75	43.51	37.87	31.64	1.39	5.24	5.64	6.23	31.64
	3	3.38	48.12	55.45	47.64	38.3	31.44	1.24	7.81	9.34	6.86	31.44
Sc	2	0.36	14.37	44.88	38.97	34.35	30.14	1.49	5.91	4.62	4.21	30.14
	2	9.69	19.92	50.6	41.24	36.02	31.27	1.47	9.36	5.22	4.75	31.27
	2	66.01	7.02	59.30	40.86	34.77	31.64	1.39	18.44	6.09	3.13	31.64
Lc	2	39.78	32.82	44.67	32.16	27.03	22.81	1.31	12.51	5.13	4.22	22.81
	2	65.88	14.70	33.45	30.10	24.82	21.38	1.36	3.35	5.25	3.44	21.38
	2	2.78	23.82	50.50	45.26	37.34	29.51	1.41	5.24	7.92	7.83	29.51
Sc	1	0.39	13.35	44.89	39.85	33.18	29.52	1.50	5.04	6.67	3.66	29.52
	1	0.34	3.75	46.77	41.24	36.01	32.44	1.43	5.53	5.23	3.57	32.44
	1	0.43	7.44	46.24	40.82	34.07	30.53	1.48	5.42	6.75	3.54	30.53
Lc	1	0.29	11.82	46.87	41.29	36.13	31.77	1.49	5.58	5.16	4.36	31.77
	1	0.20	6.72	48.60	43.99	38.43	32.87	1.40	4.61	5.56	5.56	32.87
	1	0.14	17.25	50.79	44.22	38.47	33.50	1.29	6.57	5.75	4.97	33.50
Control	0	8.27	9.66	45.30	38.59	30.76	25.43	1.53	6.71	7.83	5.33	25.43
	0	0.61	4.08	42.02	37.02	31.39	26.65	1.62	5.00	5.63	4.74	26.65
	0	0.30	15.57	42.34	37.97	31.62	27.02	1.59	4.37	6.35	4.60	27.02

C.1 Location of Research Sites

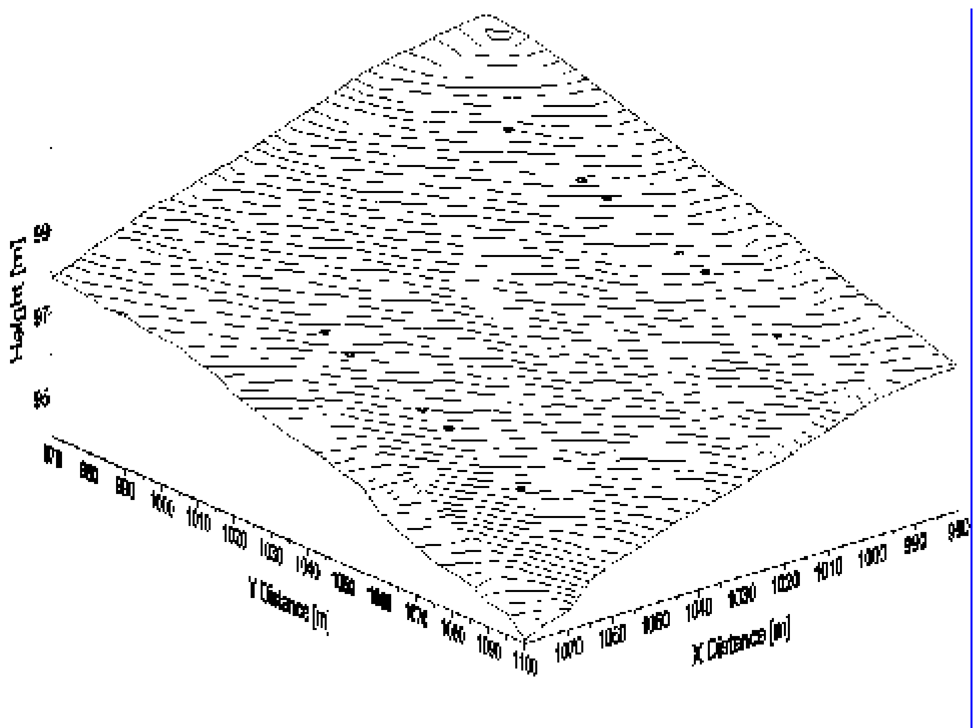




AGRICULTURE AND AGRI-FOOD CANADA

LOCATION OF RESEARCH SITES

C.2 Elevation at Research Sites



Loam Site

Clay Loam Site

C.3 Baseline Site Characterization

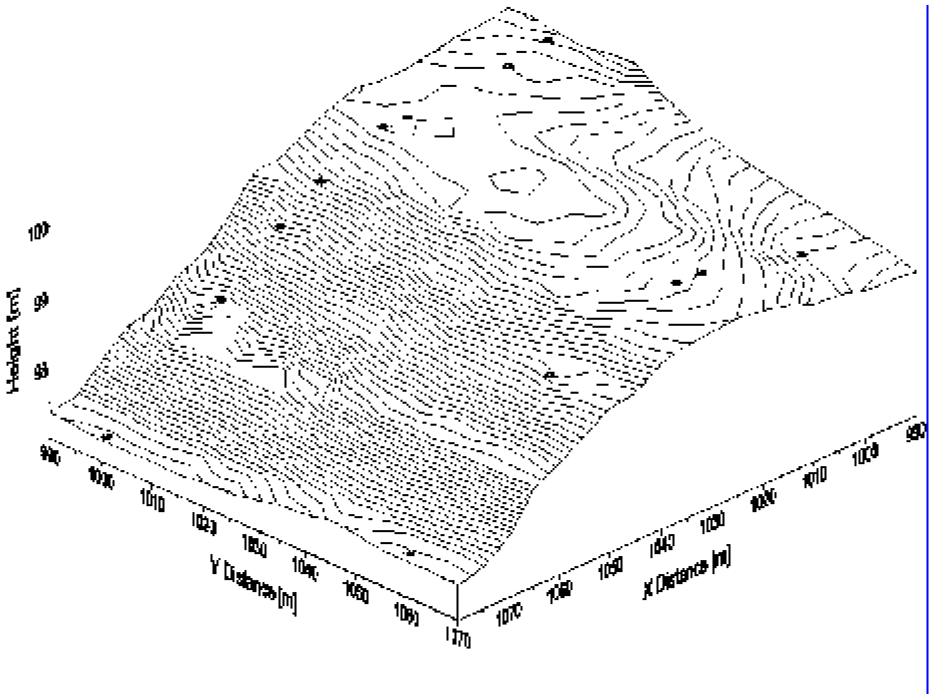

Height [m]
Y Distance [m]
X Distance [m]

Table C.1 Analysis of Inorganic Elements (mg kg^{-1}) in Soils with Depth (cm)

Element	Loam			Clay loam			MOEE upper limit normal[1]	Mean natural background levels of metals in agricultural soils of Ontario[2,3]
	0-20	20-40	40-60	0-20	20-40	40-60		
Co	7.3	8.0	9.3	12.3	16.3	13.7	25	4.4
Cd	1.0	1.0	1.7	1.3	1.7	2.3	3	0.56
Cr	5.7	6.3	4.0	16.3	24.0	16.0	50	14.3
Pb	16.7	17.3	20.3	22.7	24.0	25.3	150	14.1
Zn	56	49.7	40.3	63.7	70.7	53.7	500	53.5
Cu	9.3	15.0	13.7	18.3	24.7	16.3	60	25.4
Ni	7.7	8.3	9.0	12.3	17.3	15.7	60	15.9
As	3.9	4.4	4.8	1.6	1.8	1.8	10	6.3
Se	.387	.377	.293	.397	.250	.197	2	not measured

1 Source: Waste Reduction Office, Ontario Ministry of the Environment. 1991. Interim Guidelines for the Production and Use of Aerobic Compost in Ontario. Queen's Printer for Ontario. pp. 7-8.
2 Source: Frank, R., K. Ishida and P. Suda. 1976. Metals in agricultural soils of Ontario. Can. J. Soil Sci. 56:181-196.
3 Based on 296 farm fields sampled to 15 cm soil depth
Note: sampling: one composite soil sample per block at each soil depth

Table C.2 Carbon and Nitrogen Analysis

Site	Soil depth cm	Total C %	Organic C %	Total N %	C:N ratio
Loam	0-20	2.0	1.9	0.206	9.3
	20-40	2.0	1.1	0.135	8.1
	40-60	3.2	0.8	0.069	12.2
Clay loam	0-20	1.7	1.5	0.182	8.4
	20-40	1.8	1.0	0.135	7.4
	40-60	3.9	1.1	0.100	10.4

Note: sampling: one composite soil sample per block at each soil depth

Table C.3 Topsoil properties and fertility levels

Parameter	units	Loam	Clay loam
Soil test P_2O_5	mg/L (rating)	21 (H)	14 (M)
	recommendation kg ha^{-1}	20	20
Soil test K_2O	mg/L (rating)	63 (M)	86 (M)
	recommendation, kg ha^{-1}	80	50
Soil test Mg	mg/L	219	99
pH		7.6	7.8
CEC (Rhoades, 1982)	cmol/kg	16.8	19.3
soil texture (Canadian Soil Survey Committee, 1979)	sand, % silt, % clay, % texture:	40 47.6 12.3 loam	34.1 43 22.9 loam
organic matter	%	3.3	3.2
K_{sat} (Reynolds, 1993)	cm/h, rating	5.04, moderate	3.82, moderate
bulk density	g/cm^3	1.50	1.46
soil moisture (Topp *et al.*, 1993)	g/100g @ saturation @ 333 mbar	29.37 18.18	31.61 20.66
water stable aggregates (Pojasok and Kay, 1990)	%	22.15	16.58

Note: sampling: single composite samples (0-15 cm) per site (fertility, CEC, psa);
one composite sample (0-15 cm) per block (water stable aggregates);
two soil cores per block (near soil surface) (hydraulic conductivity, bulk density and moisture retention)

C.4 Agronomic practices used in main trial

Practice	loam site	clay loam site
previous crop (1993)	soybeans	winter wheat
fall (1993) tillage	none	chisel plow
spring (1994) tillage	single pass with S-tine cultivator to incorporate compost	single pass with cultivator with rolling harrows to incorporate compost; single pass with packer after planting
planting 1994	May 30, Pioneer variety	May 23, Pioneer 3902
fertilizer 1994	1) preplant: 67 kg K_20 ha^{-1} bulk spread; 2) at planting: 78 kg N ha^{-1} (70 lbs N ac^{-1}) as UAN (28%) spray application; 56 kg ha^{-1} 10-34-0; 3) after planting: 45 kg N ha^{-1} as urea broadcast [Total application: 129 kg N ha^{-1}; 19 kg P_20_5 ha^{-1}; 67 kg K_20 ha^{-1}]	1) preplant: 129 kg ha^{-1} 18-32-16 bulk spread 2) at planting: 56 L ha^{-1} 6-24-6; 314 L ha^{-1} of UAN sprayed [Total application: 115 kg N ha^{-1}; 55 kg P_20_5 ha^{-1}; 24 kg K_20 ha^{-1}]
weed control 1994	tank mix 2.4 L ha^{-1} atrazine and 1 L ha^{-1} Pardner (June 16); tank mix 0.75 Banvel and 0.1 kg ha^{-1} Ultim (June 28)	tank mix 0.1 kg ha^{-1} Ultim and 0.5 L ha^{-1} Pardner (June 16)
harvest 1994	October 17, 18	October 18, 20
fall (1994) tillage	none	none
spring (1995) tillage	single pass with disc to incorporate compost	2 passes with disc to incorporate compost
planting 1995	May 20; Pioneer 3921	May 20; Pioneer 3921
fertilizer 1995	1. at planting: 4 US gal ac^{-1} 10-34-0 2. after planting (May 26): 80 kg K_2O ha^{-1} as 0-0-60; 127 kg N ha^{-1} as NH_4NO_3 broadcast with Val Mar [Total application: 131 kg N ha^{-1}; 13 kg P_20_5 ha^{-1}; 80 kg K_20 ha^{-1}]	1. at planting: 4 US gal ac^{-1} 10-34-0 2. after planting (May 26): 50 kg K_2O ha^{-1} as 0-0-60; 146 kg N ha^{-1} as NH_4NO_3 broadcast with Val Mar [Total application: 150 kg N ha^{-1}; 13 kg P_20_5 ha^{-1}; 50 kg K_20 ha^{-1}]
weed control 1995	Primextra Light & Banvel	Ultim & Pardner (June 15)
harvest 1995	October 20, 24, 25	October 23, 24
fall (1995) tillage	none	none
spring (1996) tillage	single pass with disc to incorporate compost	2 passes with disc to incorporate compost
planting 1996	June 3; Funk 4030	June 2; Asgrow 1923 soybeans
fertilizer 1996	1. 4 US gal ac^{-1} 10-34-0 at planting 2. after planting (June 28): 80 kg K_2O ha^{-1} as 0-0-60; 127 kg N ha^{-1} as NH_4NO_3 broadcast with Val Mar [Total application: 131 kg N ha^{-1}; 13 kg P_20_5 ha^{-1}; 80 kg K_20 ha^{-1}]	4 US gal ac^{-1} 6-24-6 [Total application: 2.3 kg N ha^{-1}; 9.2 kg P_20_5 ha^{-1}; 2.3 kg K_20 ha^{-1}]
weed control 1996	Ultim & Pardner & atrazine directed postemerge (Aug. 2)	Pursuit & Roundup preplant (June 1); Assure postemerge (June 26)
harvest 1996	November 11, 12	October 17

Note:

Herbicide Brand/Trade name - common name
Assure - quizalofop-ethyl
Banvel - dicamba
Pardner - bromoxynil
Primextra Light - metolachlor/atrazine
Pursuit - imazethapyr
Roundup - glyphosate
Ultim - nicosulfuron/rimsulfuron

C.5 Compost Application Rates Achieved in Main Trial

Year	Source	Site	Moisture Content, % (moisture/wet weight)	Wet Rate, Mg ha^{-1}	Dry Rate, Mg ha^{-1}
1994	Sc	loam	55	99	45
		clay loam	53	111	52
		mean	**54**	**105±2.5**	**48±1.3**
	Lc	loam	56	100	44
		clay loam	56	112	49
		mean	**56**	**106±3.1**	**47±1.6**
1995	Sc	loam	47	102	54
		clay loam	47	106	56
		mean	**47**	**104±0.93**	**55±0.52**
	Lc	loam	55	135	61
		clay loam	55	142	64
		mean	**55**	**138±1.7**	**63±0.78**
1996	Sc	loam	55	115	52
		clay loam	56	113	50
		mean	**55**	**114±0.83**	**51±0.45**
	Lc	loam	51	120	58
		clay loam	53	124	59
		mean	**52**	**122±0.43**	**59±0.43**

C.6 Average Compost Analysis Applied at Sites for 1994, 1995, and 1996

Sampling Parameter, units	Lc Compost			Sc Compost			MOEE Guidelines (OMOE, 1991)
	1994	1995	1996	1994	1995	1996	
pH	8.2	7.6	7.6	8.0	7.6	8.3	5.5 - 8.5 [3]
Total N, %	1.05	0.94	1.19	1.24	0.99	1.54	0.6 [1]
Total P, %	0.17	0.15	0.17	0.29	0.21	0.23	0.25 [1]
Total K, %	0.98	0.37	0.45	2.5	0.79	1.22	0.20 [1]
SAR	1.5	0.4	1.3	4.3	8.9	9.5	<5 [3]
EC, mS cm^{-1} (1994 from sat'd paste; 1995 and 1996 from 2:1 water:compost)	0.4	4.5	0.6	0.5	9.7	1.7	<3.5 [3]
Organic C, %	24	19	21	30	27	25	
Total Zn, mg kg^{-1}	117	115	61	384	455	177	500 [2]
Total Cu, mg kg^{-1}	26	26	33	86	132	52	60 [2]
Total Mn, mg kg^{-1}	252	274	n.m.	495	663	n.m.	
Total Ni, mg kg^{-1}	56	8	18	42	13	17	60 [2]
Total Cd, mg kg^{-1}	5.5	<2	<1	5	<2	<1	3 [2]
Total Cr, mg kg^{-1}	84	7	16	68	17	24	50 [2]
Total Co, mg kg^{-1}	8	5	8	14	14	9	25 [2]
Total Pb, mg kg^{-1}	38	30	16	40	37	35	150 [2]
Total As, mg kg^{-1}	nm	nm	2.5	nm	nm	2.4	10 [2]
Total Se, mg kg^{-1}	nm	nm	<0.5	nm	nm	<0.5	2 [2]
Total Hg, mg kg^{-1}	nm	nm	.04	nm	nm	0.07	0.15 [2]
Total Mo, mg kg^{-1}	nm	nm	<2.5	nm	nm	<2.5	2 [2]

1. typical minimum for good compost quality
2. maximum concentration
3. typical of good compost quality

nm not measured

C.7 Nitrogen Response Curves

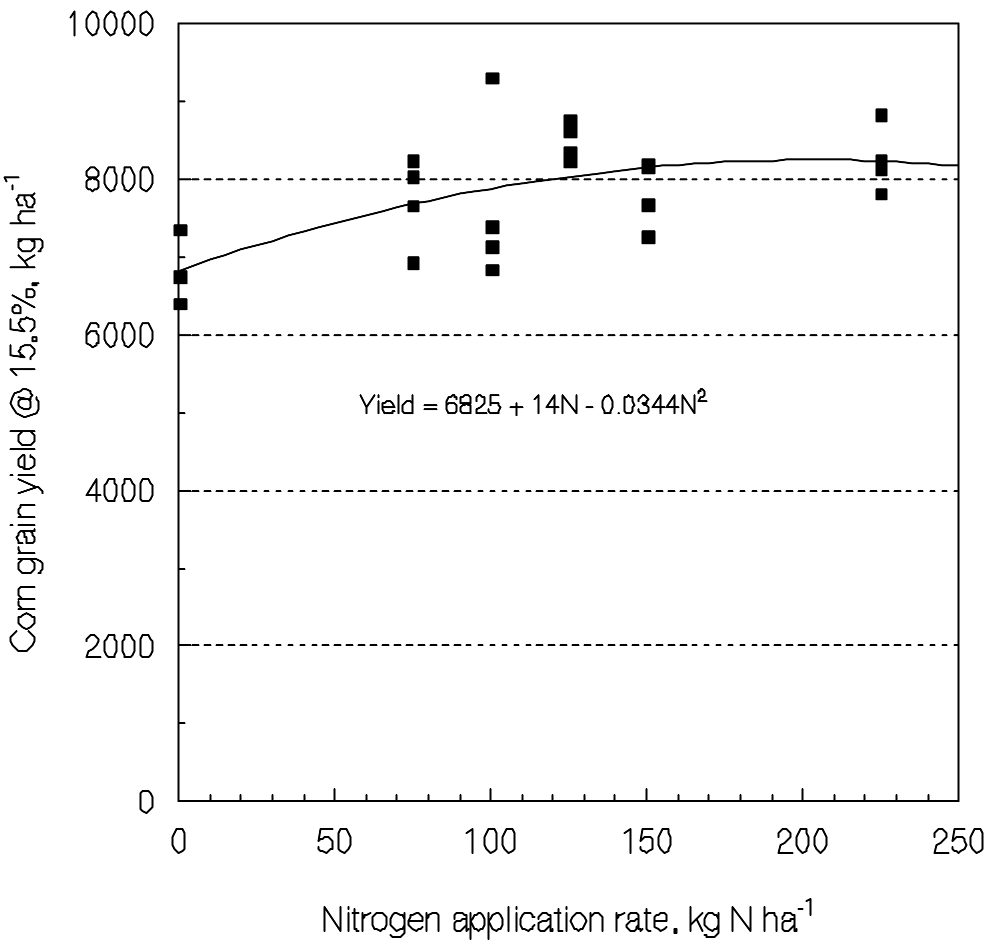


Figure 1 Nitrogen response for corn at loam site, 1994

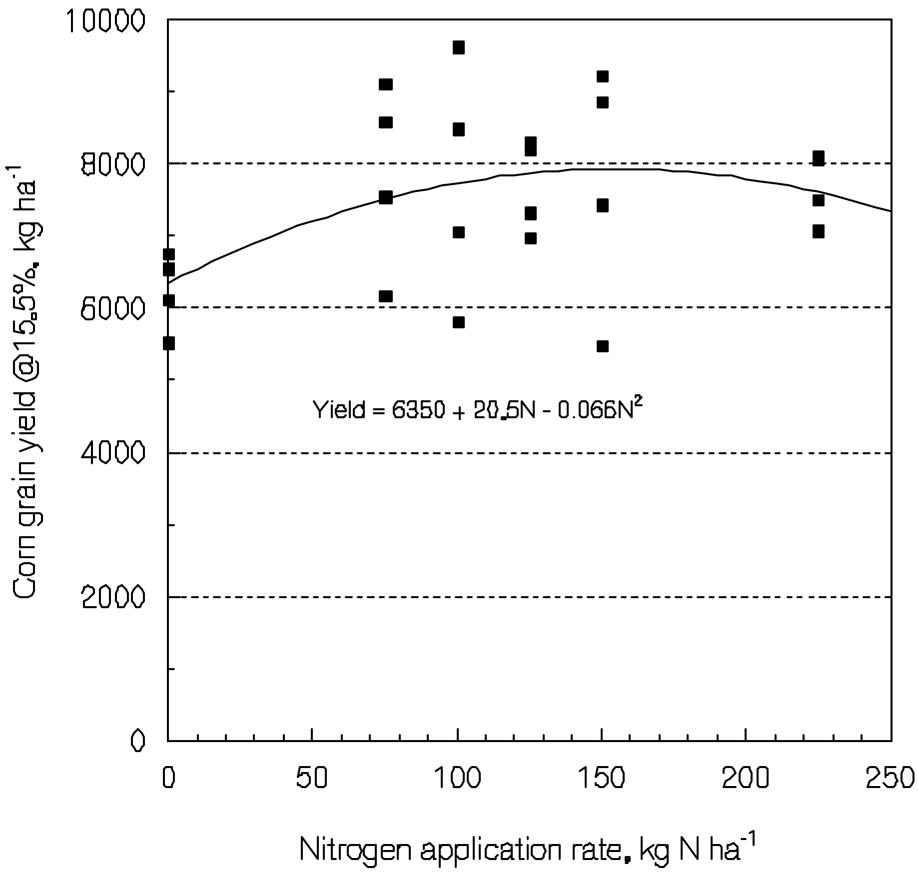


Figure 2 Nitrogen response for corn at loam site, 1995

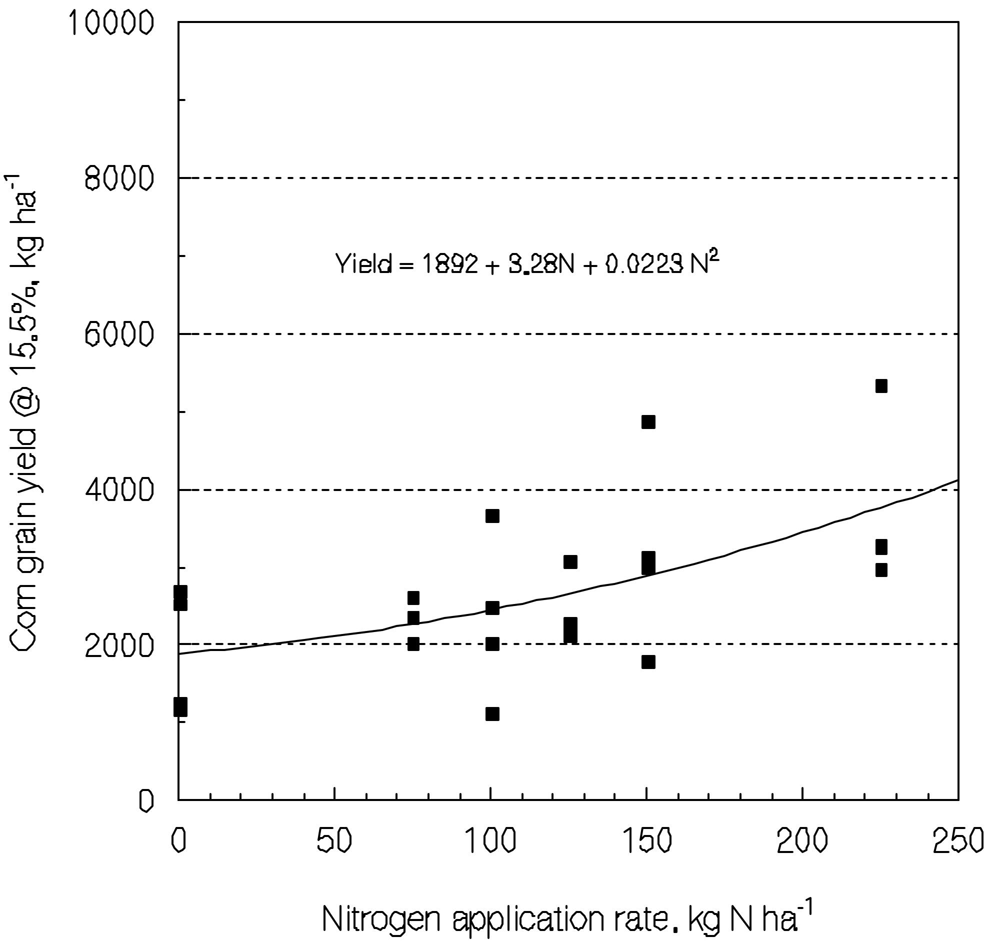


Figure 3 Nitrogen response for corn at loam site, 1996.

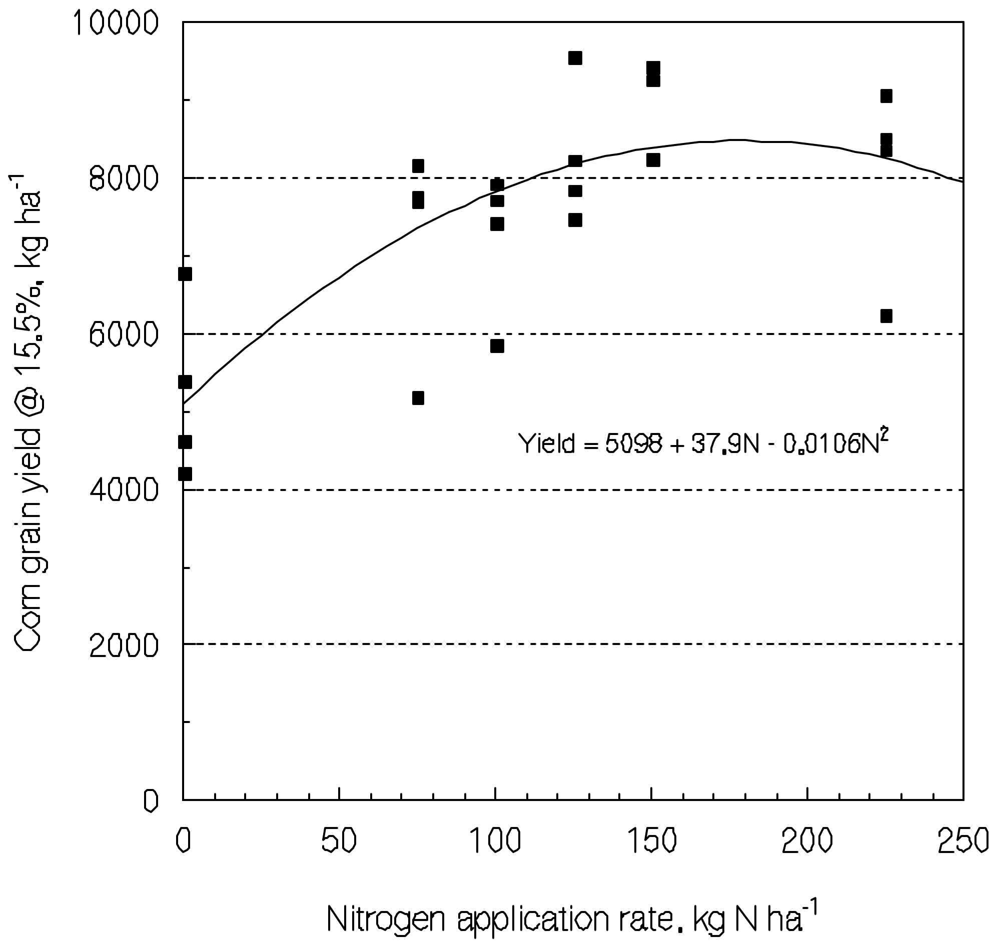


Figure 4 Nitrogen response for corn at clay loam site, 1994.

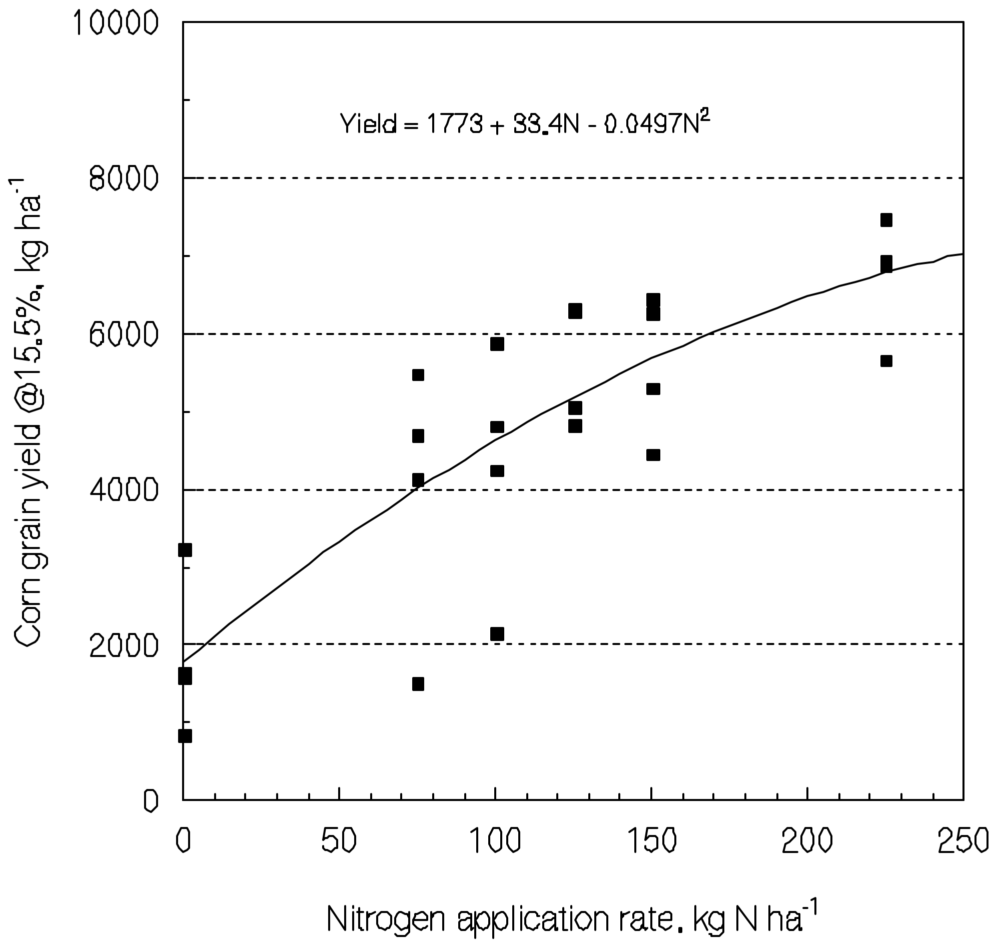


Figure 5 Nitrogen response for corn at clay loam site, 1995.

C.8 Monthly total rainfall and potential evapotranspiration

Year	Month	Rainfall.	Potential	Rainfall -
Loam site				
1994	June (146)	43.5	67	
	July	37.5	119	
	August	100.0	102	
	September	39.0	64	
		220	**352**	**-132**
1995	June	38.5	133	
	July	43.6	152	
	August	108.6	120	
	September	46.6	93	
		237.3	**498**	**-260.7**
1996	June	119.2	(76 from clay loam site)	
	July	121.4	133	
	August	38.6	131	
	September	178.6	100	
		457.8	**440**	**17.8**
Clay loam site				
1994	June (146)	49.8	76	
	July	37	134	
	August	54.5	107	
	September	27	69	
		168.3	**386**	**-217.7**
1995	June	25.7	134	
	July	78	150	
	August	107.2	124	
	September	55	92	
		265.9	**500**	**-234.1**
1996	June	95	76	
	July	114.4	116	
	August	40.8	133	
	September	171.1	90	
		421.3	**415**	**6.3**

C.9 Emergence (plants m^{-2}) and Silking date (days after planting) for loam site

Compost source	Tillage	First Year of application	1994			1995			1996		
			emerg. 16 DAP	emerg. 23 DAP	silking, DAP	emerg. 13 DAP	emerg. 20 DAP	silking, DAP	emerg. 16 DAP	emerg. 22 DAP	silking, DAP
Control			5.9	6.6	68	5.9	7.5	68	6.3	6.4	76
Sc	incorporated	1994	6.5	6.5	65	6.0	7.8	67	7.3	7.3	74
	surface	1994	5.9	6.4	65	5.9	7.6	67	5.6	6.1	77
Lc	incorporated	1994	6.3	6.8	66	4.9	7.2	67	5.8	6.2	74
	surface	1994	6.4	6.7	65	5.9	7.4	67	6.9	7.2	76
Sc	incorporated	1995				5.9	7.3	67	7.2	7.3	74
	surface	1995				5.8	7.2	67	6.9	7.0	77
Lc	incorporated	1995				6.0	7.6	67	6.3	6.5	72
	surface	1995				6.0	7.7	67	6.4	6.6	76
Sc	incorporated	1996							5.6	5.7	77
	surface	1996							6.2	6.2	74
Lc	incorporated	1996							6.6	6.8	72
	surface	1996							6.7	7.0	75
ANOVA P:		Control	.215	1.0	.005	.889	.977	.077	.643	.494	.494
		Compost	.564	.290	.804	.546	.865	.769	.978	.562	.030
		Tillage	.491	.628	.464	.609	.932	.769	.978	.783	.002
		Year				.487	.865	.769	.219	.144	.694
		Compost x Tillage	.263	.903	.236	.381	.500	.384	.034	.038	.102
		Compost x Year				.334	.047	.384	.024	.008	.618
		Tillage x Year				.487	1.0	.384	.442	.506	.056
		Compost x Tillage x Year				.546	.799	.769	.008	.026	.042

C.10 Emergence (plants m^{-2}), Silking date (days after planting), and soybean nodule mass (g pl^{-1} x 10^{-3}) for clay loam site

Compost source	Tillage	First Year of application	1994			1995			1996 (soybeans)		
			emerg. 16 DAP	emerg. 23 DAP	silking, DAP	emerg. 13 DAP	emerg. 20 DAP	silking, DAP	emerg. 14 DAP	emerg. 22 DAP	nodule mass
Control			5.3	5.7	66	5.5	7.4	67	46	50	345
Sc	incorporated	1994	4.5	4.8	70	6.2	7.2	68	45	49	395
	surface	1994	6.0	6.2	72	6.0	7.2	71	41	52	517
Lc	incorporated	1994	5.1	5.7	70	6.2	7.2	66	45	53	548
	surface	1994	6.3	6.5	68	6.7	7.6	67	48	51	413
Sc	incorporated	1995				5.0	7.0	68	44	49	437
	surface	1995				6.6	7.4	67	48	51	449
Lc	incorporated	1995				6.6	7.8	67	46	50	463
	surface	1995				6.5	7.3	69	44	48	443
Sc	incorporated	1996							44	51	453
	surface	1996							46	48	464
Lc	incorporated	1996							48	53	506
	surface	1996							44	49	504
ANOVA P:		Control	.708	.666	.010	.098	.619	.230	.896	.905	.004
		Compost	.195	.050	.130	.060	.081	.030	.467	.683	.224
		Tillage	.002	.005	.882	.130	.474	.004	.898	.514	.922
		Year				.673	.544	.506	.947	.662	.449
		Compost x Tillage	.602	.345	.204	.371	.410	1.0	.537	.302	.027
		Compost x Year				.548	.544	.004	.608	.751	.786
		Tillage x Year				.312	.474	.323	.864	.523	.976
		Compost x Tillage x Year				.053	.053	.007	.197	.857	.051

C.11 Leaf nitrogen content (%), and Corn grain yield (kg ha^{-1} @ 15.5%) for loam site

Compost source	Tillage	First Year of application	1994	1995			1996		
			Yield	Leaf N	Yield (+N)	Yield (-N)	Leaf N	Yield (+N)	Yield (-N)
Control			6908	3.2	8659	6884	2.6	3861	2231
Sc	incorporated	1994	8266	3.0	9353	6626	2.5	4574	3235
	surface	1994	7593	3.0	9058	6583	2.4	3456	1985
Lc	incorporated	1994	8145	3.1	9207	7740	2.7	4513	2926
	surface	1994	7829	3.1	9750	7922	2.2	3854	2431
Sc	incorporated	1995		3.2	9333	6914	2.5	3909	2248
	surface	1995		3.1	9114	7008	2.2	3368	2213
Lc	incorporated	1995		3.2	9388	7939	2.4	4721	2401
	surface	1995		3.1	9862	8189	2.4	4188	2361
Sc	incorporated	1996					2.6	3179	2370
	surface	1996					2.3	3809	2085
Lc	incorporated	1996					2.6	4562	2412
	surface	1996					2.0	3667	2520
ANOVA P:		Control	.023	.168	.012	.210	.271	.603	.422
		Compost	.883	.273	.074	<.000	.702	.001	.323
		Tillage	.212	.478	.498	.630	.002	.002	.033
		Year		.199	.657	.248	.704	.161	.120
		Compost x Tillage	.646	.637	.043	.704	.480	.168	.215
		Compost x Year		.791	.730	.805	.550	.124	.857
		Tillage x Year		.471	.992	.838	.234	.215	.058
		Compost x Tillage x Year		.784	.846	.944	.212	.038	.608

C.12 Corn leaf nitrogen content (%), Corn grain yield (kg ha^{-1} @ 15.5% moisture), Soybean yield (kg ha^{-1} @ 14% moisture) and Soybean Grain N content for clay loam site

Compost source	Tillage	First Year of application	1994	1995			1996	
			Yield	Leaf N	Yield (+N)	Yield (-N)	Soybean Yield	Grain N
Control			7320	2.5	5930	2513	3219	6.37
Sc	incorporated	1994	5274	2.2	5576	2903	2997	6.20
	surface	1994	4521	1.9	3607	2596	3591	6.23
Lc	incorporated	1994	6058	2.4	5829	2935	3253	6.15
	surface	1994	7032	2.3	6257	2659	3249	6.38
Sc	incorporated	1995		2.3	5922	2829	3030	6.34
	surface	1995		2.3	5213	2556	3186	6.27
Lc	incorporated	1995		2.4	6292	4058	3144	6.36
	surface	1995		2.1	4883	2982	3261	6.27
Sc	incorporated	1996					3158	6.16
	surface	1996					3009	6.06
Lc	incorporated	1996					3176	6.25
	surface	1996					2972	6.13
ANOVA P:		Control	.020	.027	.133	.495	.700	.192
		Compost	.008	.133	.001	.299	.846	.409
		Tillage	.849	.005	<.000	.254	.247	.711
		Year		.321	.222	.426	.105	.097
		Compost x Tillage	.144	.927	.050	.643	.120	.640
		Compost x Year		.030	.001	.354	.720	.903
		Tillage x Year		.988	.496	.645	.038	.205
		Compost x Tillage x Year		.076	.001	.617	.213	.660

C.13 Ammonium and nitrate nitrogen levels (mg N L^{-1}) in soil solution at loam site

Compost source	Tillage	First Year of application	1994				1995				1996	
			30 cm		80 cm		30 cm		80 cm		30 cm	
			NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
Control			.263	16.3	.203	22.3	.336	7.2	.840	6.9	.147	8.0
Sc	incorporated	1994	.867	13.3	.350	12.5	.587	10.0	.617	7.5	.523	12.4
	surface	1994	.593	9.4	.180	8.9	.377	7.6	.443	6.6	.333	5.8
Lc	incorporated	1994	.447	11.7	.123	11.9	.447	7.9	.437	3.3	.193	8.3
	surface	1994	.540	13.0	.313	11.5	.483	6.4	.637	6.4	.337	6.9
Sc	incorporated	1995					.640	10.0	.503	9.1	.203	12.6
	surface	1995					.550	6.6	.427	6.1	.260	7.2
Lc	incorporated	1995					.843	4.8	.443	7.3	.190	11.2
	surface	1995					.460	7.3	.367	6.5	.213	6.6
Sc	incorporated	1996									.203	6.4
	surface	1996									.303	7.8
Lc	incorporated	1996									.163	9.6
	surface	1996									.200	7.2
ANOVA P:		Control	.060	.023	.323	.008	.055	.706	.948	.746	.342	.768
		Compost	.213	.589	.178	.485	.857	.081	.710	.104	.187	.715
		Tillage	.695	.357	.558	.879	.155	.273	.700	.656	.667	.004
		Year					.186	.448	.456	.161	.193	.395
		Compost x Tillage	.210	.142	.011	.964	.916	.121	.474	.092	.550	.724
		Compost x Year					.742	.784	.815	.394	.697	.497
		Tillage x Year					.502	.461	.669	.100	.842	.179
		Compost x Tillage x Year					.232	.244	.477	.604	.397	.192

C.14 Ammonium and nitrate nitrogen levels (mg N L^{-1}) in soil solution at clay loam site

Compost source	Tillage	First Year of application	1994				1995				1996	
			30 cm		80 cm		30 cm		80 cm		30 cm	
			NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
Control			.310	11.4	.163	6.0	.290	3.6	.422	4.6	.253	9.5
Sc	incorporated	1994	.540	7.8	.300	3.8	.540	3.4	.420	3.1	.333	7.4
	surface	1994	.503	5.5	.080	2.2	.720	3.4	.370	2.7	1.97	8.6
Lc	incorporated	1994	.427	16.0	.130	5.2	.593	9.2	.413	4.5	.210	7.5
	surface	1994	.213	10.8	.077	5.5	.540	7.5	.527	1.7	.290	6.1
Sc	incorporated	1995					.337	4.8	.323	3.1	.237	8.5
	surface	1995					.663	4.0	.310	2.7	.257	11.4
Lc	incorporated	1995					.437	7.7	.403	3.3	.253	10.7
	surface	1995					.455	4.6	.363	5.8	.260	5.2
Sc	incorporated	1996									.253	9.8
	surface	1996									.227	8.4
Lc	incorporated	1996									.227	6.7
	surface	1996									.257	13.8
ANOVA P:		Control	.358	.920	.872	.139	.003	.336	.906	.089	.772	.818
		Compost	.070	.055	.362	.045	.347	.160	.274	.674	.289	.756
		Tillage	.228	.248	.166	.533	.318	.803	.981	.440	.298	.808
		Year					.199	.947	.246	.082	.310	.650
		Compost x Tillage	.381	.638	.380	.353	.108	.403	.871	.910	.365	.834
		Compost x Year					.791	.343	.829	.315	.312	.806
		Tillage x Year					.238	.946	.786	.196	.357	.688
		Compost x Tillage x Year					.997	.705	.534	.232	.409	.238

C.15 Dissolved Organic Carbon levels (mg C L^{-1}) in soil solution

Compost source	Tillage	First Year of application	Loam site					Clay loam site				
			1994		1995		1996	1994		1995		1996
			30 cm	80 cm	30 cm	80 cm	30 cm	30 cm	80 cm	30 cm	80 cm	30 cm
Control			41.5	21.7	70.8	40.8	9.8	23.9	52.0	94.8	52.7	19.5
Sc	incorporated	1994	62.6	100.0	26.5	15.4	11.2	48.4	36.4	136.4	30.6	19.0
	surface	1994	46.3	23.6	18.7	22.8	12.9	55.7	16.9	27.8	34.9	32.2
Lc	incorporated	1994	49.8	36.8	29.6	20.4	10.0	55.8	17.5	15.3	35.5	11.3
	surface	1994	29.1	19.9	25.0	24.7	15.3	55.1	23.4	46.6	83.4	18.6
Sc	incorporated	1995			21.6	19.6	11.3			129.2	37.2	15.8
	surface	1995			30.6	18.2	11.2			41.4	36.1	17.9
Lc	incorporated	1995			69.2	30.3	18.0			16.7	36.3	15.1
	surface	1995			21.3	23.0	11.9			36.8	35.5	22.5
Sc	incorporated	1996					13.3					25.8
	surface	1996					10.9					16.1
Lc	incorporated	1996					18.9					16.7
	surface	1996					21.5					15.2
ANOVA P:		Control	.774	.003	.013	.006	.364	.204	.094	.009	.015	.779
		Compost	.225	.001	.175	.398	.101	.857	.656	.027	.050	.056
		Tillage	.155	<.001	.240	.907	.944	.860	.624	.960	.074	.231
		Year			.501	.766	.411			.474	.210	.882
		Compost x Tillage	.730	.001	.225	.732	.864	.831	.371	.079	.122	.970
		Compost x Year			.477	.741	.461			.871	.040	.153
		Tillage x Year			.820	.441	.554			.827	.027	.050
		Compost x Tillage x Year			.186	.915	.604			1.0	.142	.578

C.16 Soil microbial biomass C (g C m^{-2}) at loam site

Compost source	Tillage	First Year of application	June 1994	August 1994	October 1994	June 1995	August 1995	June 1996	August 1996
Control			118	123	124	150	96	117	36
Sc	incorporated	1994	177	97	125	130	93	154	92
	surface	1994	147	145	146	151	120	222	76
Lc	incorporated	1994	118	110	125	146	96	128	50
	surface	1994	141	125	141	161	108	167	133
Sc	incorporated	1995				132	115	187	83
	surface	1995				133	112	163	67
Lc	incorporated	1995				137	101	120	119
	surface	1995				143	102	145	54
Sc	incorporated	1996						101	59
	surface	1996						166	103
Lc	incorporated	1996						108	69
	surface	1996						141	96
ANOVA P:		Control	.414	.819	.427	.562	.389	.239	.218
		Compost	.279	.838	.815	.290	.282	.058	.744
		Tillage	.896	.083	.130	.254	.255	.035	.653
		Year				.266	.645	.136	.959
		Compost x Tillage	.371	.331	.861	.964	.726	.898	.800
		Compost x Year				.788	.626	.608	.984
		Tillage x Year				.438	.206	.318	.248
		Compost x Tillage x Year				.767	.542	.486	.326

C.17 Soil microbial biomass C (g C m^{-2}) at clay loam site

Compost source	Tillage	First Year of application	June 1994	August 1994	October 1994	June 1995	August 1995	June 1996	August 1996
Control			132	144	144	125	96	116	143
Sc	incorporated	1994	136	169	180	141	157	188	237
	surface	1994	138	177	201	103	178	212	261
Lc	incorporated	1994	141	149	167	108	94	164	162
	surface	1994	157	178	162	123	126	152	202
Sc	incorporated	1995				127	140	183	130
	surface	1995				130	133	184	198
Lc	incorporated	1995				99	137	158	121
	surface	1995				112	116	117	207
Sc	incorporated	1996						150	137
	surface	1996						147	75
Lc	incorporated	1996						125	115
	surface	1996						122	159
ANOVA P:		Control	.584	.281	.057	.509	.022	.183	.622
		Compost	.507	.612	.093	.053	.005	.038	.655
		Tillage	.626	.342	.605	.819	.551	.741	.226
		Year				.776	.475	.142	.029
		Compost x Tillage	.691	.600	.368	.042	.965	.453	.396
		Compost x Year				.268	.033	.869	.324
		Tillage x Year				.194	.069	.826	.440
		Compost x Tillage x Year				.152	.551	.867	.740

C.18 Soil Properties in Relation to Annual Compost Additions at the Loam Site

Compost source	Years of application	Soil test Mn (mg L^{-1})	Soil pH	EC (mS cm^{-1})	WSA (%)	Organic C in A horizon (%)	Organic C in A horizon (kg C ha^{-1})
Control		30	7.3	0.12	16.0	1.74	67,340
Sc	3	39	7.3	0.18	14.5	2.39	84,206
Lc		34	7.4	0.17	16.8	2.26	85,899
Sc	2	38	7.4	0.18	14.3	2.01	74,591
Lc		35	7.4	0.16	15.0	2.12	80,482
Sc	1	37	7.3	0.16	17.9	1.94	75,351
Lc		36	7.5	0.15	17.7	1.87	70,016
ANOVA P:	Control	.002	.290	.004	.998	.008	.030
	Compost	.031	.045	.104	.770	.724	.829
	Year	.939	.584	.321	.703	.006	.035
	Compost x Year	.473	.688	.896	.945	.532	.421

C.19 Soil Properties in Relation to Annual Compost Additions at the Clay Loam Site

Compost source	Years of application	Soil test Mn (mg L^{-1})	Soil pH	EC (mS cm^{-1})	WSA (%)	Organic C in A horizon (%)	Organic C in A horizon (kg C ha^{-1})
Control		21	7.5	0.16	12.4	1.73	63,894
Sc	3	24	7.6	0.19	9.4	2.32	71,675
Lc		24	7.6	0.17	14.5	2.27	75,864
Sc	2	27	7.6	0.17	10.4	2.06	70,037
Lc		24	7.7	0.17	11.6	1.96	73,747
Sc	1	21	7.5	0.16	10.5	1.69	51,605
Lc		25	7.6	0.17	9.4	1.76	53,649
ANOVA P:	Control	.259	.332	.477	.180	.070	.790
	Compost	.932	.390	1.00	.040	.996	.429
	Year	.602	.298	.506	.142	.005	.012
	Compost x Year	.424	.952	.292	.017	.764	.932

C.20 Surface hydraulic properties from field and soil cores, loam site, individual data points

Compost source	Years of application	K_S cm hr^{-1}	K_F cm hr^{-1}	Soil water content, %				Bulk density, g cm^{-3}	Porosity, %			
				h=0 cm	h=10cm	h=333 cm	h=15,000		Macro	Drainable	Available	Residual
Sc	3	12.59	5.43	58.9	51.56	45.89	41.14	1.08	7.34	5.67	4.75	41.14
	3	0.16	11.43	54.60	51.23	41.89	34.39	1.29	3.37	9.34	7.50	34.39
	3	110.51	28.20	50.90	47.12	41.98	39.01	1.28	3.78	5.14	2.97	39.01
Lc	3	1.09	10.32	52.49	44.60	36.10	31.91	1.22	7.89	8.50	4.19	31.91
	3	133.15	16.56	52.37	46.69	40.16	36.29	1.31	5.68	6.53	3.87	36.29
	3	14.00	16.68	53.41	42.78	32.32	27.53	1.25	10.63	10.46	4.79	27.53
Sc	2	134.95	21.39	55.95	48.05	41.21	36.86	1.16	7.90	6.84	4.35	36.86
	2	1.86	21.87	51.79	48.03	38.28	30.31	1.25	3.76	9.75	7.97	30.31
	2	0.24	5.28	48.18	45.09	37.61	29.04	1.42	3.09	7.48	8.57	29.04
Lc	2	1.66	23.19	53.6	48.7	37.42	32.00	1.23	4.90	11.28	5.42	32.00
	2	0.70	3.81	46.91	42.14	36.67	28.57	1.44	4.77	5.47	8.10	28.57
	2	1.68	20.04	47.07	44.72	39.68	31.14	1.37	2.35	5.04	8.54	31.14
Sc	1	3.65	11.13	52.67	46.09	37.72	29.49	1.26	6.58	8.37	8.23	29.49
	1	4.13	26.22	53.3	43.58	33.51	29.00	1.18	9.72	10.07	4.5	29.00
	1	4.28	21.36	52.46	46.14	36.65	30.72	1.26	6.32	9.49	5.93	30.72
Lc	1	0.48	8.4	50.99	44.68	38.86	32.93	1.30	6.31	5.82	5.93	32.93
	1	1.36	22.02	49.98	39.45	34.83	28.01	1.36	10.53	4.62	6.82	28.01
	1	0.60	17.28	50.99	44.68	38.86	32.93	1.30	6.31	5.82	5.93	32.93
Control	0	3.69	5.31	47.29	40.33	33.97	31.63	1.32	6.96	6.36	2.34	31.63
	0	0.10	18.21	45.91	40.98	33.40	28.88	1.39	4.93	7.58	4.52	28.88
	0	1.67	13.56	48.95	43.08	33.96	29.65	1.32	5.87	9.12	4.31	29.65

C.21 Surface hydraulic properties from field and soil cores, clay loam site, individual data points

Compost source	Years of application	K_S cm hr^{-1}	K_F cm hr^{-1}	Soil water content, %				Bulk density, g cm^{-3}	Porosity, %			
				h=0 cm	h=10cm	h=333 cm	h=15,000		Macro	Drainable	Available	Residual
Sc	3	0.01	11.91	51.25	46.67	40.94	36.58	1.33	4.58	5.73	4.36	36.58
	3	1.45	34.32	54.15	47.81	42.63	39.63	1.29	6.34	5.18	3.00	39.63
	3	0.08	30.18	46.54	40.79	36.33	33.00	1.49	5.75	4.46	3.33	33.00
Lc	3	1.58	37.44	53.52	46.31	39.39	34.78	1.36	7.21	6.92	4.61	34.78
	3	20.9	8.13	48.75	43.51	37.87	31.64	1.39	5.24	5.64	6.23	31.64
	3	3.38	48.12	55.45	47.64	38.3	31.44	1.24	7.81	9.34	6.86	31.44
Sc	2	0.36	14.37	44.88	38.97	34.35	30.14	1.49	5.91	4.62	4.21	30.14
	2	9.69	19.92	50.6	41.24	36.02	31.27	1.47	9.36	5.22	4.75	31.27
	2	66.01	7.02	59.30	40.86	34.77	31.64	1.39	18.44	6.09	3.13	31.64
Lc	2	39.78	32.82	44.67	32.16	27.03	22.81	1.31	12.51	5.13	4.22	22.81
	2	65.88	14.70	33.45	30.10	24.82	21.38	1.36	3.35	5.25	3.44	21.38
	2	2.78	23.82	50.50	45.26	37.34	29.51	1.41	5.24	7.92	7.83	29.51
Sc	1	0.39	13.35	44.89	39.85	33.18	29.52	1.50	5.04	6.67	3.66	29.52
	1	0.34	3.75	46.77	41.24	36.01	32.44	1.43	5.53	5.23	3.57	32.44
	1	0.43	7.44	46.24	40.82	34.07	30.53	1.48	5.42	6.75	3.54	30.53
Lc	1	0.29	11.82	46.87	41.29	36.13	31.77	1.49	5.58	5.16	4.36	31.77
	1	0.20	6.72	48.60	43.99	38.43	32.87	1.40	4.61	5.56	5.56	32.87
	1	0.14	17.25	50.79	44.22	38.47	33.50	1.29	6.57	5.75	4.97	33.50
Control	0	8.27	9.66	45.30	38.59	30.76	25.43	1.53	6.71	7.83	5.33	25.43
	0	0.61	4.08	42.02	37.02	31.39	26.65	1.62	5.00	5.63	4.74	26.65
	0	0.30	15.57	42.34	37.97	31.62	27.02	1.59	4.37	6.35	4.60	27.02