# Non-Nutrient Value of Manure

# - Literature Review -

**March 2006**

**For:**
**Ontario Ministry of Agriculture, Food and Rural Affairs**

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## Executive Summary

It is well-known that livestock manure and sewage biosolids have value in the production of horticultural and field crops. In the past, however, any economic analysis of the value associated with manure and biosolids has considered only the nutrient value - mainly the value of N, P and K. This literature review examined the non-nutrient value. There have been a range of studies that have looked at the non-nutrient value of manure and biosolids, even if the focus has not been to establish an economic value. The main findings of the review:

**Agronomic Considerations**

**a) Soil physical quality**

- Applications of cattle (beef and dairy) and poultry manure, as well as sewage biosolids can decrease soil bulk density in a variety of soil types, cropping systems, and climates. However, based on experience with cattle manure, it appears that there will be little or no impact on bulk density when existing organic matter levels in the soils are high.
- Very little information was found on the effects of swine manure applications on soil physical quality. One study cautioned the use of liquid swine manure on crops that returned very little organic matter to the soil. The manure improves soil microbial activity, breaking down the native OM without replacing it.
- No information was found on how other manure types, such as horse, sheep, mink, rabbit, etc., may affect soil physical quality.
- No information was found comparing the relative impacts on soil physical quality of "typical" liquid manure or sewage biosolids with anaerobically digested manures or sewage biosolids.
- Soil-water characteristics generally improved with the addition of cattle, dairy and poultry manure and sewage biosolids, including:
    - neutral or increased infiltration capacity of soils;
    - neutral or increased water holding capacity of soils; and
    - decreased evaporation rates.
- Manure and biosolids additions improved aggregate stability in most cases, which may lead to:
    - Lower energy costs associated with spring tillage
    - Less risk of soil structural damage if tillage is done when soil moisture levels are high
    - Better crop seedling emergence and root development, which may positively impact crop yield.
- High rates of cattle manure application may lead to aggregate dispersion due to the high salt content of cattle manure.
- Cattle manure additions to soil can provide a liming effect, thus reducing the need for additional amounts of commercial lime inputs.
- Manure and sewage biosolids can have a neutral to positive effect on crop yields, including corn silage, grain corn and alfalfa.

- No studies were found that looked into the effects of soil quality on horticultural crop yields, where soil quality was influenced by the application of manure and sewage biosolids.

**b) Risk of crop failure**

- Only one study could be found that specifically looked at how improved soil-water characteristics affected a crop's susceptibility to crop failure. This study showed significant yield gains in fields treated with manure over fields which had not received manure in a year where there was a drought followed by torrential rains.

**c) General soil ecology**

- The addition of manure and sewage biosolids to soils can positively affect soil microbial, enzyme, and earthworm populations. The degree to which they are affected may vary according to the properties of the manure/biosolids.
- Enzyme activity may be decreased when manure/biosolids are anaerobically digested.
- Earthworm activity has been shown to be negatively impacted by machinery traffic, but earthworm activity has also been shown to recover when the traffic is removed.
- Because microbial and earthworm populations and enzyme activity can positively affect aggregate stability, many of the economic benefits related to aggregate stability, such as lower fuel costs for tillage machinery and better soil conditions for root growth can be attributed to these organisms and enzymes in the soil.

**d) Weed seed spread and survival**

- There have only been a few studies examining the effect of manure additions to weed seed spread and survival.
- Manure and inorganic fertilizer additions have similar effects on weed biomass.
- Surface application of manure may favour weed biomass compared to manure injection.
- Manure as a mulch can control weeds in apple seedling nurseries.

**e) Control of plant pathogens**

- Manure additions to soil, especially manures with high N levels, have shown the potential for controlling soil pathogens - Verticillium wilt, potato scab, *R. solanacearum* 1609, branched broomrape, and some plant parasitic nematodes; pathogens associated with potato production.
- The ability of manure to control pathogens is quite variable.

**<u>Environmental Considerations</u>**

**a) Water quality and quantity**

- There are risks of contamination to surface water and groundwater quality associated with manure and biosolids application to soils. However, these risks can be minimized using known management practices.
- The addition of manure and biosolids to soil may improve water infiltration and soil water capacity, particularly in saturated conditions, which may reduce peak flows in streams and lower the risks of any related negative impacts.

**b) Soil Loss**

- Land application of manure and biosolids can reduce soil loss from fields, which may:
    - o Decrease sedimentation in streams, and thus reduce negative impacts on stream wildlife and stream flow capacity.
    - o Lower the risk of transferring soil-borne nutrients and pathogens, such as phosphorus and *Cryptosporidium* to surface waters.
    - o Keep fertile topsoil on the land and thus minimize soil degradation.

The report includes several recommendations for follow-up work and future research that should be considered to fill in some of the knowledge gaps that exist.

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## 1.0 Introduction

The intensification of agricultural production and increased pressure from society to protect consumers and the environment have contributed to the development of Ontario legislation regarding nutrient management and source water protection. The Ontario *Nutrient Management Act, 2002*, discourages over-application of nutrients on crop land. In some cases, livestock producers (manure "generators") generate more manure than they can, within regulations, apply to their own land base. As new nutrient management plans require livestock producers to adhere to provincial standards for nutrient applications, other land, where the nutrients are deemed necessary, may be needed for manure application. For instance, based on U.S. swine slurry operations, if proposed P limits were implemented, there would be an estimated 250% increase in land needs and between 24-41% increase in time needed for manure application (2004b). It is likely that Ontario's new nutrient management regulations will impact manure application practices, which will almost certainly increase the need for applications to "crop producer" (i.e. non-generator) land. For U.S. swine operations, the costs of manure transportation and application exceeded the N value on 58% and 15% of slurry and non-agitated lagoon operations, respectively (Lory et al. 2004a). With the cost of transporting manure more than short distances exceeding the nutrient value of manure, there is no economically viable alternative to land application (Daniel et al. 1998). In some cases, a crop producer may be anxious to receive the manure, based on the perceived nutrient value alone. A crop producer may be concerned about the possibility of compaction from manure applicaiton. In other cases, the manure "generator" must convince a neighbouring non-generator to accept the manure. However, Lory et al. (2004a) and others (Vietor et al., 2002; Lory et al., 2004b) typically did not consider the non-nutrient value of manure.

The usual approach in assessing the value of manures and biosolids is to consider the nutrient content of N, P, and K and the availability of these nutrients. A value is then assigned based on nutrient needs of the crops and current costs of inorganic fertilizer. In certain conditions, other macronutrients (Ca, Mg, and S) as well as micronutrients (B, Cl, Cu, Fe, Mn, Mo, Ni and Zn) could also be considered beneficial and included as part of the nutrient value of the manure or biosolid. This approach does not give any value to other qualities of manure that may help to set it apart from inorganic fertilizer. The true value of manure may only be realized by also describing manure impacts on soil quality, which will impact crop yields and farm income. Moreover, it may be possible to change the current perspective of manure as a "waste product", a view still held by many, to manure as an "economic agricultural resource" (Araji *et al.* 2001). It is important to document this non-nutrient value in an effort to make more efficient use of manure resources in Ontario, which will likely impact the economics of transport or value of manure use as a resource.

Worldwide, especially in organic and sustainable agriculture, manure is used as a source of organic matter (OM) to improve soil quality as well as the traditional source of crop nutrients (Kumar et al. 2006). Land application of animal manure is known to increase soil OM and improve a number of soil quality properties including soil tilth, water-holding capacity, soil structure and aggregate stability, water infiltration rates, soil biota diversity and activity, and soil fertility as well as reducing spring runoff (Grande et al. 2005) and soil erosion.

Soil quality and good soil management are vital components of sustainable crop production because soil supports the fundamental physical, chemical, and biological processes that must take place in order to support plant growth. How well functions like water infiltration, runoff, root growth and nutrient uptake are performed depends on soil quality. Characteristics such as soil texture, OM, water-holding capacity, bulk density, biological activity, and others can be used to characterize soil quality. The agriculture industry in Ontario is primarily located in the Mixedwood Plains ecozone, which covers the Great Lakes - St. Lawrence River Valley and contains the most productive soils in Canada. In general, the soil was developed from carbonate-rich Paleozoic bedrock with deposits from ancient water bodies and glaciers.

Ontario farms produce a variety of field crops, fruits and vegetables. The top five field crops (by area) grown in Ontario are soybeans, hay, grain corn, winter wheat and corn silage. Similarly, the top five fruit crops grown in Ontario are apples, grapes, peaches, strawberries and pears, while the top five vegetable crops are sweet corn, peas (green), tomatoes, beans (green and wax), and carrots. The area grown for each of these crops is included in Table 1, as well as crop specific nutrient application recommendations for each crop (assuming moderate soil test levels for phosphorous and potash).

Most farmers realize the importance of good soil management and many have adopted practices such as crop rotation, crop residue management, and soil conservation measures to maintain soil quality. However, the true value of such soil management practices on farm income and long-term economic viability, and environmental quality is very difficult to quantify. Moreover, there is no economic estimate available to farmers of the true value of soil quality improvements made by manure.

In Ontario, the total volume of manure produced consists of 63%, 31%, and 6% from cattle, swine, and poultry, respectively. This is applied to approximately 18.4% of the total tillable land (Table 2) (Marchand and McEwan 2001). From 1986 to 1996, Ontario's annual manure production decreased by 7.5% from 33.4 billion litres to 30.9 billion litres and is projected to drop to 27.1 billion litres by 2010 (Marchand and McEwan 2001). Overall, the manure source (i.e. type of livestock), type (i.e. solid vs. liquid), storage, treatment of manure (e.g. anaerobic digestion and composting) and application method affects the nutrient composition and non-nutrient value of manure. Therefore, the composition of manure will affect the potential for manure to impact overall soil quality. Likewise, other soil organic amendments, such as biosolids from sewage treatment, pulp and paper waste, composted waste (e.g. spent mushroom substrate and fruit and vegetable waste), are used on farm lands and need to be quantified in terms of the ability to improve and/or maintain soil quality. The potential benefits of manure and other soil amendments on soil quality may only be realized over a longer time frame. In contrast, the potential nutrient benefits are likely more immediate.

Table 1- Area grown and nutrient requirements of the five (by area) field crops, fruit crops and vegetable crops in Ontario.

| Crop | Hectare (ha*) (2000-2004 Average) | General Recommended kg/ha* | N-P-K use lb/ac |
|---|---|---|---|
| | Field Crops | | |
| Soybean | 875,336 | 0-27-40 | 0-25-40 |
| Hay (less than ⅓ legume) | 950,203 | 111-35-22 | 100-30-20 |
| Grain corn | 728,030 | 180†-22-57 | 160†-20-50 |
| Winter wheat | 286,518 | 89†-22-22 | 80†-20-20 |
| Fodder corn | 126,667 | | |
| | Fruit Crops | | |
| Apples | 7,802 | 101-27-40 | 90-25-35 |
| Grape | 6,132 | 35-27-101 | 30-25-90 |
| Peach | 2,254 | 101-27-22 | 90-25-20 |
| Strawberry | 1,459 | 84-35-57 | 75-30-50 |
| Pear | 834 | 101-27-22 | 90-25-20 |
| | Vegetable Crops | | |
| Sweet Corn | 17,063 | 89-22-40 | 80-20-35 |
| Peas (green) | 9,731 | 17-22-40 | 15-20-35 |
| Tomatoes | 7,509 | 101-96-128 | 90-85-115 |
| Beans (green and wax) | 4,196 | 40-22-40 | 35-20-35 |
| Carrots | 3,356 | 101-101-79 | 90-90-70 |

† Grain corn and winter wheat nitrogen rates are dependant on expected yield.
All field crop values are adapted from the OMAFRA (2002) publication 811.
All fruit values are adapted from the OMAFRA (2004) publication 360.
All vegetable values are adapted from the OMAFRA (2006) publication 363.
*All values are converted from their original imperial values using the conversions of:
1 ac = 0.404686 ha and 1 lb = 0.45359 kg

Table 2- Tillable area and application of liquid and solid livestock manure by region in Ontario

| Area name | Total tillable area (ha) | Area receiving liquid manure (% of tillable land) | Area receiving solid manure (% of tillable land) |
|---|---|---|---|
| Huron | 249,089 | 7 | 12.9 |
| Bruce | 181,766` | 3.5 | 21.3 |
| Perth | 180,374 | 12.3 | 16.9 |
| Wellington | 156,997 | 9 | 20.5 |
| Oxford | 152,205 | 11.6 | 12.3 |
| Niagara | 67,879 | 4.8 | 15.8 |

(Reproduced from Marchand and McEwan 2001)

To provide the reader with a general idea the range of nutrient contents of a variety of organic materials, Table 3 has been included in this review. The quantity of nutrients that eventually is available to the crop is less than the total amount applied. This is demonstrated in the table for nitrogen (N). A smaller amount of N becomes available in subsequent years as organic N is mineralized. In addition, some N is available for leaching or runoff and some is lost to the atmosphere. This nutrient budget can be rather complex and takes into account such factors as soil temperature and moisture condition and timing of incorporation.

The ratio of carbon to N (C:N) has typically been used in the past by the compost industry. However, typical values are included in Table 3, as they may have an impact on soil properties, as described later in this report.

Table 3 – Typical properties of various materials considered in this literature review

| | Dry Matter | Total N | Available N† | Available $P_2O_5$ | Available $K_2O$ | C:N |
|---|---|---|---|---|---|---|
| | % | ------------------------ | kg/t | ------------------------ | | |
| **Manure** | | | | | | |
| Solid Dairy | 19.9 | 11 | 1.6 | 1.3 | 5 | 25-30 |
| Solid Beef | 27.4 | 5.9 | 1.2 | 1.3 | 6.4 | 25-30 |
| Solid Poultry | 49.0 | 20 | 9.5 | 8.2 | 11.8 | 13-30 |
| Liquid Swine | 3.6 | 3.7 | 2.6 | 1.0 | 1.8 | 5-7 |
| Liquid Dairy | 6.5 | 2.9 | 1.6 | 0.64 | 2.9 | 8-13 |
| Liquid Beef | 5.2 | 2.5 | 1.7 | 0.7 | 1.9 | 8-13 |
| Liquid Poultry | 8.0 | 7.5 | 6.1 | 2.5 | 3.4 | NA |
| **Other** | | | | | | |
| Sewage biosolids (aerobic) | 2.0 | 1.2 | 0.3 | 0.6 | NA | <20 |
| Sewage biosolids (anaerobic) | 4.4 | 2.8 | 1.2 | 1.9 | NA | <20 |
| Sewage biosolids (de-watered) | 33.8 | 12.2 | 1.0 | 9.8 | NA | <20 |

Properties reported on an “as-is” basis.
† Available N is based on spring application, incorporated within 24 hours.
All values except C:N ratios are adapted from OMAFRA and TFIO (1998).
C:N ratios are from NRAES(1999).

This literature review was intended to give a better understanding of the value of manure, over and above the nutrients it contains. It was also based on the premise that one of the best uses of livestock manure is to spread it onto a suitable land base and use it as an input in the production of horticultural and field crops. This literature review focused on published scientific research and grey literature (eg. extension publications) pertaining to the non-nutrient value of manure. An emphasis was placed on results from areas having similar soils, climate and agricultural practices to those of Ontario. While the main intent was to address livestock manure, other organic soil amendments used on farms (e.g. biosolids) were considered. In addition, the review examined other jurisdictions and how they communicated (i.e. extension materials) the benefits of manure. The main objectives of this literature review were to provide documentation that would:

- Assess and promote the value of livestock manure and other organic substrates (e.g. biosolids and other land applied "wastes") from an organic soil amendment perspective to current generators of manure so that economics of application can be reassessed on more than commercial fertilizer equivalent,
- Provide information to non-generators to assist in the decision-making process so they can determine if they want to use manure on their land base and thereby, increase the demand for manure on non-generator lands.

# 2.0 Non-nutrient value of manure and sewage biosolids

The non-nutrient value of adding manure and sewage biosolids as an organic soil amendment will be reviewed in this section in two parts. Part 1 will review the non-nutrient value of manure and sewage biosolids in terms of agronomic considerations. Part 2 will look at environmental considerations.

## Part 1 – Agronomic Considerations

### 2.1 Manure and sewage biosolids additions affect soil quality characteristics

Soil quality can be defined as the capacity of a soil to function within "ecosystem boundaries" to sustain biological productivity, maintain environmental quality, and promote plant and animal health. Improvements in physical soil quality characteristics are generally indicated by increases in water infiltration, macroporosity, aggregate size and stability, and soil OM (Kremer and Li 2003).

Applications of manure and sewage biosolids have long been thought to improve soil physical characteristics. Literature reviews over the last 30 years (Hayes and Naidu 1998; Khaleel et al. 1981; Sweeten and Mathers 1985; Wallingford et al. 1975) have summarized that additions of manure to soil can lead to increased OM content, aggregate stability and porosity; decreased bulk density; and improved infiltration rates, hydraulic conductivity, and water-holding capacity (Table 4).

Table 4- Summary of the general trends in soil properties after the addition of manure as identified by four literature reviews of the last 30 years.

| Characteristic | Effect of manure | Reference(s) |
|---|---|---|
| Organic matter content | Increased | Sweeten and Mathers (1985); Hayes and Naidu (1998) |
| Bulk density | Decreased | Wallingford *et al.* (1975); Khaleel *et al.* (1981); Sweeten and Mathers (1985); Hayes and Naidu (1998) |
| Infiltration rates | Improved | Wallingford *et al.* (1975); Khaleel *et al.* (1981); Sweeten and Mathers (1985) |
| Hydraulic conductivity | Improved | Wallingford *et al.* (1975) |
| Water holding capacity | Improved | Wallingford *et al.* (1975); Khaleel *et al.* (1981); Sweeten and Mathers (1985); Hayes and Naidu (1998) |
| Porosity | Increased | Sweeten and Mathers (1985); Hayes and Naidu (1998) |
| Aggregate stability | Increased | Wallingford *et al.* (1975); Khaleel *et al.* (1981); Sweeten and Mathers (1985); Hayes and Naidu (1998) |

Many changes in soil quality after manure additions are linked to the effects of OM content on soil structure and biological activity (Bronick and Lal 2005; Tisdall and Oades 1982). The humic and polysaccharide molecules of the OM can act as binding agents or fuel for soil organism activity (Hayes and Naidu 1998). Manure type and application rate, as well as soil texture characteristics, therefore affect the degree to which manure additions affect soil quality characteristics.

Bulk density is sometimes used as an indicator of soil quality. The decreased bulk density in manured soils may partially result from a dilution effect caused by mixing of the added organic material with the more dense mineral fraction of the soil. However, it is likely that its impact on porosity and aggregation contributes more to the lower bulk densities. Manure applications increase the relative number of small pores (i.e. <30*u*m diameter) in the soil, especially for coarse textured soils (Hayes and Naidu 1998).

Changes in OM content and soil bulk density also lead to changes in the soil-water characteristics. For example, increases in OM have been linked to increases in water infiltration. Good infiltration can reduce surface runoff, erosion, and evaporation rates. High evaporation rates have been linked to inefficient use of irrigation water (Boyle et al. 1989).

Another indicator of soil physical quality is aggregate stability. Aggregate stability is defined as the ability of soil aggregates to resist rearrangement and breakdown into primary particles by various disruptive forces, especially the effects of water (Gregorich et al. 2002). If a soil has low binding capacity, it means that soil aggregates can break down easily, which is a symptom of poor soil structure. Poor soil structure can inhibit root growth which limits the efficient exploration of the soil profile for water and nutrients. It can also leave soil more susceptible to ponding of water at the soil surface, higher runoff volumes, and increased prevalence of root disease, or following drying, the formation of a surface crust which restricts germination and seedling emergence (Hayes and Naidu 1998).

The following section will review the literature as to how manure additions to soil affect soil bulk density, soil-water characteristics, and aggregate stability.

### 2.1.1 Cattle manure as a soil amendment

#### 2.1.1.1 Soil bulk density

As indicated in Table 5, there are several studies where the addition of solid cattle manure resulted in decreased soil bulk density (Arriaga and Lowery 2003; Castellanos and Muñoz 1985; Mathers and Stewart 1980; Tiarks *et al.* 1974; Unger and Stewart 1974; Sommerfeldt and Change 1985;1987), or had a neutral effect on bulk density (Benbi *et al.* 1998; Eghball 2002) . No reports of cattle manure application resulting in increased bulk density were found in the literature. Details of each of these studies are included below.

Table 5 - Summary of studies reviewed examining the effect of cattle manure on bulk density.

| Location (years of study) | Manure type | Manure quantity applied (Mg/ha/yr) | Soil Type | Effect on bulk density (% change from control) | Reference |
|---|---|---|---|---|---|
| Wisconsin (10) | Liquid*; solid** | 15.6*; and 13.7** (avg) | Dubuque silt loam | Decrease (10) | Arriaga and Lowery (2003) |
| North Central Mexico (3) | Solid | 0, 30, 60, 120, 240 | Calcareous clayey soil | Decrease (4-8) | Castellanos and Muñoz (1985) |
| Texas (11) | Solid | 0, 22, 67, 134, 268 | Pullman clay loam | Decrease (3-10) | Mathers and Stewart (1980) |
| Lethbridge, Alberta (13) | Solid | 0, 30, 60, 90 †; 0, 60, 120, 180 ‡ | Dark Brown Chernozemic clay loam | Decrease (12 -25†; 12-35‡) | Sommerfeldt and Chang (1985) (1987) |
| Texas (4) | Solid | 0, 22, 67, 134, 268 | Pullman clay loam | Decrease (3 -18) | Unger and Stewart (1974) |
| Mid-west US (3) | Solid | 0, 90, 180, 360 | Sharpsburg silty clay loam | Decrease (4 -14) | Tiarks *et al.* (1974) |
| India (20) | Solid | 10 | Fetehpur loamy sand | Neutral | Benbi *et al.* (1998) |
| Nebraska (4) | Solid | Variable$^{\beta}$ | Sharpsburg silty clay loam | Neutral | Eghball (2002) |

† application rate on non-irrigated land.
‡ application rate on irrigated land.
* liquid manure was applied on the land during years one to four.
** solid manure was applied on the same land during years five to ten.
β manure applied to meet N and P crop needs of 151 and 25.8 kg/ha, respectively.

Arriaga and Lowery (2003) applied manure onto a badly eroded Dubuque silt loam over 10 years. Liquid manure was fall applied/injected for first four years of experiment at loading rates of 7.5, 10.8, 16.7, and 27.4 Mg/ha, respectively (avg 15.6 Mg/ha/yr); and solid manure was fall applied/incorporated for the remaining 6 years, at loading rates of 14, NR[1], 19.8, 10, NR, 11.9, 13 Mg/ha, respectively (avg. 13.7). The site was planted to corn (*Zea mays* L.). They reported significant decreases (10%) in soil bulk density in the top layers (0-7.6 cm) of the soil where manure had been applied, particularly in the areas where their had been only slight erosion. However, bulk density was not as affected at lower depths (15–22.6 cm; or 30–37.6 cm), or where erosion rates had been moderate or severe. The study does not numerically report these values.

Castellanos and Muñoz (1985) applied and incorporated dairy manure to a calcareous clayey soil with 1.15% OM in north central Mexico at rates of 30, 60, 120 and 240 Mg/ha over three consecutive years. The check treatment received

[1] NR- not recorded

60 kg N/ha per cutting. All treatments (manured and check) received 240 kg $P_20_5$/ha at planting. They found soil bulk density to decrease compared to the control from1.33 to 1.28 and 1.22 g/cc for manure application rates of 120 and 240 Mg/ha, respectively. The changes to bulk density were not reported for any of the other application rates.

Mathers and Stewart (1980) applied beef feedlot manure onto a Pullman clay loam over at 10 year period at rates of 0, 22, 67, 134, and 268 Mg/ha/yr. The plots were planted for the first six years to hybrid grain sorghum (*Sorghum bicolor* (L.) Monech "RS-671" for 3 yrs and "Dekalb E-59" for the next 3 yr), followed by a corn-wheat rotation (*Zea mays* L. "PAG 492"; *Triticum aestivum* L. "TAM 101). Compared to the control (bulk density 1.35 $Mg/m^3$), manure applications decreased bulk density by 3, 4, 2, and 10%, at rate of 22, 67, 134, and 268 Mg/ha/yr, respectively.

Sommerfeldt and Chang (1985; 1987) fall-applied and incorporated since 1973 onto non-irrigated and irrigated (150 mm water per year) plots at the Lethbridge Research Centre in Alberta and planted to barley. Manure rates were 0, 30, 60, and 90 Mg/ha for non-irrigated plots and 0, 60, 120, and 180 Mg/ha for irrigated plots. These rates are essentially the recommended, and two and three times the recommended rates of application. While they clearly demonstrated that application of excessive amounts of manure (two to three times recommended rates based on nutrient content) substantially decreased soil bulk density (16-25% on the non-irrigated plots and 27 – 35% on the irrigated plots), application of manure at *recommended* rates also lowered soil bulk densities and draw-bar draft resistance relative to the unmanured control (by 12% in both irrigated and non-irrigated plots). This was somewhat surprising given the relatively good tilth of the soil (well-drained Dark Brown Chernozemic, clay content >15%) at the start of the study. They suggested that the benefits of manure application would presumably be greater if the soil was of poorer tilth to start with.

Tiarks *et al.* (1974) applied cattle feedlot manure to a Sharpsburg silty clay loam in the spring at 0, 90, 180, and 360 Mg/ha/yr and incorporated it at different depths. The plots were planted to a sorghum-sudangrass hybrid (*Sorghum bicolour L.*) in year one of the experiment and corn silage in years two and three. Their results showed a linear relationship between manure application rate and soil bulk density. Compared to the control, soil bulk density decreased from 1.05 to 0.90 $g/cm^3$ at the highest rate of application (360 Mg/ha/yr), and particle density decreased from 2.63 to 2.50 $g/cm^3$.

Unger and Stewart (1974) applied cattle feedlot wastes to a Pullman clay loam in Texas during the spring of four successive years at 5 different rates (0, 22, 67, 134 or 268 Mg/ha[2]). The feedlot wastes were lightly incorporated and planted to grain sorghum (*Sorghum bicolor* L. Moench). The field plots were irrigated.

[2] Mg/ha the units "metric tonnes per hectare" will be used throughout the paper.

Their results, shown in Table 6, indicate decreasing bulk density with increasing rates of manure. Compared to control, bulk density was decreased by 3 to 18%, depending on the rate of application.

Table 6 - Effect of cattle feedlot waste application rate on organic matter content, bulk density, and water content.

| Determination | Feedlot waste application rate, Mg/ha/yr | | | | |
|---|---|---|---|---|---|
| | 0 | 22 | 67 | 134 | 268 |
| Organic matter (%) | 1.41c[†] | 2.14b | 2.59a | 2.79a | 2.58a |
| Bulk Density ($g/cm^3$) | 1.37a | 1.33a | 1.28ab | 1.20bc | 1.12c |
| Water content (% by wt) | | | | | |
| Saturation | 32.4c | 33.7c | 36.7bc | 41.0ab | 45.8a |
| -0.2 bars matric potential | 28.0b | 28.6b | 29.2b | 30.3ab | 32.3a |
| -1.5 bars matric potential | 25.6b | 26.2b | 26.2b | 27.2b | 29.9a |
| -15 bars matric potential | 18.2a | 18.9a | 18.7a | 19.5a | 19.3a |

† Row values for any determination followed by the same letter or letters are not significantly different from each other.
‡ F-test indicated significant differences at 10% level of confidence.
(adapted from Unger and Stewart 1974).

Benbi *et al.* (1998) showed that, though additions of farmyard manure increased the soil organic carbon (C) levels significantly (by 44%) compared to plots which just received inorganic fertilizer, there was not a significant change in the soil bulk densities. Their study applied farmyard manure in combination with inorganic fertilizer to a Fetehpur loamy sand soil in India at a rate of 10 Mg/ha for 20 years. The field plots were planted to a maize-wheat-fodder cowpea cropping cycle. NPK inorganic fertilizer application was 150-33-62 kg/ha for maize, 150-33-30 kg for wheat, and 20-18-17 kg/ha for cowpea.

Eghball (2002) found soil bulk density to be unaffected by solid cattle manure, cattle compost or fertilizer application rates based on crop N- or P-requirement. The 4 year study was conducted at the University of Nebraska Agricultural Research Centre. Corn was grown on the Sharpsburg silty clay loam and beef manure and beef compost was applied in the autumn. He suggested this was because the amount of OM applied was not enough to change the soil bulk density in the silty clay loam soil with an original OM content of 31 g/kg (i.e. 3.1%).

In summary, the addition of cattle manure decreases soil bulk density in a variety of soil types, cropping systems, and climates. When antecedent organic matter levels in soils are high, additions of cattle manure may not affect bulk density.

However, in such conditions, improvements of soil physical conditions have been recognized even when applying at rates to meet nutrient requirements.

#### 2.1.1.2 Soil-water characteristics

Soil-water characteristics are greatly affected by the soil's physical properties. Table 7 summarizes a number of studies that have reported on the effects of cattle manure additions to water retention, water infiltration, and/or soil-water evaporation (Table 7). These studies are outlined below.

Miller *et al.* (2002) fall-applied and incorporated cattle manure for 24 years onto non-irrigated and irrigated (150 mm water per year) plots at the Lethbridge Research Centre in Alberta. Manure rates were 0, 30, 60, and 90 Mg/ha for non-irrigated plots and 0, 60, 120, and 180 Mg/ha for irrigated plots. These rates are essentially the recommended, and two and three times the recommended rates of application. Barley (*Hordeum vulgare* L. 'Galt') was grown from 1973 to 1995 on the plots, followed by one year of canola (*Brassica napus* L.). In 1997, the dryland plots were planted with barley, followed by a year of triticale (*Triticosecale rimpaui* Whittm.). The irrigated plots were planted to corn in 1997 and 1998. Soil-water characteristics were monitored during 1997 and 1998. They found that manure additions did not significantly affect water retention at the 0 – 10 cm depth (surface) for the dryland conditions. Manure applications did significantly increase soil water retention at the 10 – 15cm depth (subsurface) by 5 to 17% under dryland conditions and 12 to 48% under irrigated conditions, and at the surface by 16 to 37% under irrigation.

Miller *et al.* (2002) found that manure additions to soil significantly increased soil-water content (SWC) in the summer, coinciding with the season of maximum crop water use. Under dryland conditions, SWC increased at the surface from 10 to 22% and at the subsurface from 11 to 21% at all rates. Under irrigation, there were significant increases in SWC, from 16 to 22%, only at the surface and only at rates ≥120 Mg/ha. Additionally, Miller *et al.* (2002) found that manure generally had no effect on infiltration under ponded water in either dryland or irrigated conditions. However, there was a significant increase (>200%) in ponded infiltration in 1998 under dryland conditions and in 1997 under irrigation at the higher levels of application. A possible reason for this was the increase in macropores (>1120 μm in diameter) noted in these treatments. More than 61% of water flowed through these macropores in the ponded-water conditions. This may result in less runoff and more infiltration during high intensity rainstorms. By contrast, the researchers found that manured soils showed little effect on water percolation during *unsaturated* conditions (Miller *et al.* 2002).

Unger and Stewart (1974) found that manure application to soil can decrease soil-water evaporation. The study (described in section 2.1.1.1) found evaporation decreased by 4.0, 3.3, 9.6, and 17.8% when manure was applied at the equivalent of 22, 67, 134 and 268 Mg/ha, respectively, compared to the control.

Table 7 - Summary of studies examining the soil-water affects of cattle manure additions to soil.

| | | Study information | | | |
|---|---|---|---|---|---|
| Soil-water characteristic | Effect of manure (% change from control) | Location (years of study) | Manure quantity applied (Mg/ha/yr) | Soil type | Reference |
| Water retention | Increased (5-48) | Lethbridge, AB (24) | 0, 30, 60, 90 †; 0, 60, 120, 180 ‡ | Dark Brown Chernozemic clay loam | Miller *et al.* (2002) |
| | (NA) | Wisconsin (10) | 15.6*; and 13.7** (avg) | Debuque silt loam | Arriaga and Lowery (2003) |
| | (NA) | Ottawa region, ON (4) | 50, 100 | Brandon loam | Ma *et al.* (2003) |
| | (NA) | India (20) | 10 | Fetehpur loamy sand | Benbi *et al.* (1998) |
| Water Infiltration (Saturated HC) | Increased (0- >200) | Lethbridge, AB (24) | 0, 30, 60, 90 †; 0, 60, 120, 180 ‡ | Dark Brown Chernozemic clay loam | Miller *et al.* (2002) |
| | (24) | India (20) | 10 | Fetehpur loamy sand | Benbi *et al.* (1998) |
| | (60-730) | Texas (11) | 22, 67, 134, 268 | Pullman clay loam | Mathers and Stewart (1980) |
| | (NA) | North Central Mexico (3) | 0, 30, 60, 120 | Calcareous clayey soil | Castellanos and Muñoz (1985) |
| Evaporation | Decreased (4-17) | Texas (4) | 0, 22, 67, 134, 268 | Pullman clay loam | Unger and Stewart (1974) |

† application on non-irrigated land;
‡ application on irrigated land;
* liquid application over years 1 to 4;
** solid application over years 4 to 10.

The Arriaga and Lowery (2003) study, which looked at manure application and its effects on an eroded soil, found that soil-water retention capacity increased with manure additions. Gains in soil water retention from manure applications in the severe erosion phase were greater than for the soils with moderate or slight erosion. The increases in soil-water retention are thought to be due to increased organic matter content in the surface soil from the manure additions, a conclusion echoed in the study by Benbi *et al.* (1998). Soil C content correlated well with water retention and bulk density (Arriaga and Lowery 2003).

In summary, the application of cattle manure has a positive effect on soil water characteristics, leading to increased water retention, increased hydraulic conductivity, increased infiltration, and decreased evaporation rates in a number of soil types, climatic conditions and application rates.

#### 2.1.1.3 Aggregate stability

Additions of cattle slurry manure increased soil aggregate stability (Munkholm *et al.* 2002). The study looked at the long-term (>100 yr) effects of 3 different fertilization methods on the mechanical properties of a sandy loam soil in Denmark. The three treatments were non-fertilized plots, mineral fertilizers (NPK) and animal manure. Mineral fertilizers had been applied since 1923, while animal manures had been applied since 1894 at mean rates of 97.5 and 146 kg total N/ha. Since 1923, the plots were in a four crop rotation of winter cereals, root crops, spring cereal undersown with a grass-clover mixture, and grass-clover. In the year of sampling, the field plots were planted to spring barley (*hordeum vlugare* L.) and winter wheat (*Triticum aestivum L.*). The non-fertilized soil had the strongest aggregates in dry conditions and weakest when wet. Manuring produced soil aggregates that were stronger when wet and weaker when dry, compared to the other two treatments. The authors suggest that manure additions to a sandy loam soil improves conditions for tillage because less energy is needed to till the soil when it is dry, and there is less risk of structural damage when wet soil is tilled.

The study by Benbi *et al.* (1998) conducted in India (described in section 2.1.1.1) found that application of farmyard manure increased aggregate stability by 12% (from 16.8 to 29.2) compared to the control. Other studies have also found that additions of cattle (Loveland and Webb 2003) and dairy (Min *et al.* 2003) manure increased aggregate stability.

The study of Sommerfeldt and Chang (1985) indicated that cattle manure additions (1873-1985) to an irrigated soil at the Lethbridge Research Centre in Alberta increased the proportion of aggregates > 1 mm. Whalen and Chang (2002) later reported on this same study site, and found that the long term (1973-1999) application of cattle manure actually increased macroaggregate dispersion when manure was applied at rates >30 Mg/ha onto dryland soils and >60 Mg/ha to irrigated soils. This result was unexpected, and they suggest this could increase the risk of soil and nutrient loss through wind erosion. Two factors were identified as possible explanations for this unusual finding. Firstly, under the dry-land conditions of this study, the electrical conductivity of manured soils was increased. It was possible that the addition of monovalent cations in the manure lead to greater soil dispersion. Secondly, the manure was being scraped from a feedlot overlying a finer textured soil than the study site. As a result, soil from the feedlot was being applied with the manure and had resulted in a decrease in the sand content of the surface soil of the study site. This could possibly have affected the aggregation of the soil (Whalen and Chang 2002). Thus, it is unlikely that under normal circumstances the application of cattle feedlot manure at normal rates would negatively impact soil aggregation.

In summary, cattle manure additions increase aggregate stability in most cases. Improved aggregate stability may reduce the energy required to till the soil when it is dry, may reduce surface crusting and the need for a replant, and/or the use of a rotary hoe to get emergence. Each of these things would minimize fuel consumption and thus reduce operation costs. It may also reduce the risk of structural damage when wet soil is tilled.

#### 2.1.1.4 Soil chemical properties

Cattle manure additions have been shown to produce a liming effect on the soil (Eghball *et al.* 2004; Vitosh *et al.* 1997). Eghball *et al*. (2004) concluded that the liming effect of manure and composted manure was due to lime in the cattle diet, which is subsequently excreted in manure. This study was conducted on a Sharpsburg silty clay loam soil in Nebraska over 3 years. Manure and compost were applied by hand in the autumn after harvest of corn and incorporated. Plots were planted to corn and irrigated during the growing season.

Similarly, Vitosh *et al.* (1997) applied loose housing beef manure for 20 years (1963 to 1982) to a Metea loamy sand soil in Michigan, planted in a continuous corn production system where both grain and silage were removed. They found that manures were able to neutralize the acidity produced by the oxidation of organic N and, to a lesser extent, organic S during manure decomposition. In contrast, soils that received inorganic fertilizers seemed to acidify soil so that lime was needed to increase soil pH.

In summary, cattle manure may produce a liming effect on the soil due to the lime additives of cattle diets. The liming value of cattle manure should not be underestimated when considering supplementary application of commercial lime. If the amount of commercial lime applied to the land can be minimized, this could provide cost-saving measures to the producer.

#### 2.1.1.5 Yield

The application of cattle manure has been shown to have variable effects on crop yields. Mathers and Stewart (1980), and Miller *et al.* (2002) found that improvement in soil quality did not necessarily lead to increased yields. By contrast, Tiarks *et al.* (1974), Arriaga and Lowery (2003), Castellanos and Muñoz (1985), and Ma *et al.* (2003) found that improvements in soil quality led to increased yield (Table 8). Vitosh *et al.* (1997) found that similar yields can be achieved regardless of whether nutrients come from manure or commercial fertilizer.

Mathers and Stewart (1980) suggested that manure rates need to be determined by considering improvements in soil quality as well as the impacts of soil quality on yield. They noted the effects of manure application on soil quality and yield in an 11 year experiment on a Pullman clay loam in Texas. The plots were planted to hybrid grain sorghum (*Sorghum bicolour* (L.)) for the first six years, followed by a corn silage-wheat (*Zea mays* L. and *Triticum aestivum* L.) rotation for the remainder of the experiment. Beef feedlot manure was applied at 22, 67, 134, 268, and 536 Mg/ha annually. Manure increased soil OM and hydraulic conductivity. Applying manure at 22 Mg/ha supplied sorghum, corn silage, and wheat with sufficient nutrients for maximum crop yields, thus making 22 Mg/ha the most efficient manure application rate - when incorporated immediately after spreading. Applying manure at higher rates improved soil physical properties (OM content, bulk density, and saturated hydraulic conductivity), but did not significantly increase yields. Miller *et al.* (2002) also found that improvements in soil water retention did not necessarily improve in crop yields.

Table 8 - Summary of studies measuring the effect on yield of cattle manure additions.

| Location (yrs of study) | Soil type | Manure quantity applied (Mg/ha) | Crop | Change in yield (% over control) | Reference |
|---|---|---|---|---|---|
| Ottawa region, ON (4) | Brandon loam | 50 and 100♦♦ | Grain maize continuous or in rotation with soybeans or alfalfa | Decrease (yr-1); increase (yr-4) | Ma *et al.* (2003) |
| Lethbridge, AB (24) | Dark brown Chernozemic clay loam | 0, 30, 60, 90†; 0, 60, 120, 180‡ | Barley, canola, triticale and corn | Neutral | Miller *et al.* (2002) |
| Alberta (3) | Low-C gray lucisolic | 28 (avg) | Canola, hulless barley, and wheat | Increase (25-50) | Lupwayi *et al.* (2005) |
| Midwest US (3) | Sharpsburg silty clay loam | 0, 90, 180, 360 | corn silage | Increase ( 0, 20, 8, 31*) | Tiarks *et al.* (1974) |
| Wisconsin (10) | Debuque silt loam | 15.6**; and 13.7β (avg) | Grain corn | Increase (19-25) | Arriaga and Lowery (2003) |
| Texas (11) | Pullman clay loam | 22, 67, 134, and 268 | Corn silage | Neutral | Mathers and Stewart (1980) |
| North central Mexico (3) | Calcareous clayey soil | 0, 30, 60, 120 | Alfalfa | Increase ( 24, 40, and 60♦) | Castellanos and Muñoz (1985) |
| Michigan (20) | Metea loamy sand | 22, 45, 67 | Continuous corn | Neutral | Vitosh *et al.* (1997) |

† application rate on non-irrigated land;
‡ application rate on irrigated land;
* increases correspond to manure application rates of 0, 90, 180, and 360 Mg/ha
** liquid application over years 1 to 4;
β solid application over years 4 to 10.
♦ increases correspond to manure application rates of 30, 60, and 120 Mg/ha, respectively
♦♦ manure applied at 50 Mg/ha for crops in rotation and at 100 Mg/ha in continuous corn

Mathers and Stewart (1980) found that very high rates of manure application (536 Mg/ha) led to lower yields, likely because high rates of application resulted in high salt and ammonia levels in the soil.

In contrast, Tiarks *et al.* (1974) found corn silage yield increased by as much as 30% (coinciding with improvements in soil quality) as cattle manure rates increased, particularly when manure was incorporated at depths of 10 cm. At this depth, yields were 14.8, 17.8, 16.0 and 19.4 Mg/ha at application rates of 0, 90, 180 and 360 Mg/ha, respectively.

Arriaga and Lowery (2003) found that application of beef manure over a 10-yr period led to corn grain yield increases of 19 and 25% in the final years of the study. Beef manure was applied to a Dubuque silt loam in Wisconsin (fall applied/injected liquid manure for first four years of experiment at loading rates of 7.5, 10.8, 16.7, and 27.4 Mg/ha, respectively; and fall applied/incorporated solid manure for the remaining 6 years, at loading rates of 14, NR[3], 19.8, 10, NR, 11.9, 13 Mg/ha, respectively). Bulk density was decreased by 10% and the hydraulic conductivity of the saturated soils doubled in the top 7.6 cm of the soil. Soil C content correlated well with water retention and bulk density. Increased yield from manure additions was likely related to an enhancement in water retention.

Castellanos and Muñoz (1985) found that alfalfa yield improved with additions of dairy manure to soil. They determined that dairy manure application on a calcareous clayey soil with 1.15% OM in north central Mexico, led to increases in dry matter yields of alfalfa of 24, 40 and 60% for the rates of 30, 60 and 120 Mg/ha of incorporated manure. The check treatment received 60 kg N/ha per cutting. All treatments (manured and check) received 240 kg P2)5/ha at planting. When manure was applied at rates higher than 120 Mg/ha, there were no further increases in yields. The authors suggest that the response of yield to dairy manure can not be explained on a nutritional basis since the nitrogen treatment did not increase yield over the control. Also all plots received enough phosphorus fertilizer at planting to satisfy crop requirements. As such, the response in yield occurred as a result of improving soil physical properties, such as increased water infiltration, improved soil aeration and decreased bulk density. Study results were gathered over a three year period.

Ma *et al.* (2003) conducted a four year field study on a Brandon loam soil and found that crop rotation and N amendments could affect corn grain yield. Plots were planted to continuous maize, maize-soybean, or maize-alfalfa rotations. N amendment strategies for the rotation plots were: no amendment; $NH_4$-$NO_3$ applied at 100 kg N/ha; and stockpiled and rotted dairy manure, both applied at 50 Mg/ha. In the continuous maize plots, fertilizer-N was applied at 200 kg/ha and manures were applied at 100 Mg/ha. Total N concentrations in the manure ranged from 19 to 24 g/kg for rotted manure and 18 to 21 g/kg for stockpiled manure. The C:N ratio of the rotted manure was generally smaller than that of the stockpiled manure, but not specifically described. They found that, initially, grain yields in the continuous maize plots treated with manure were generally 5% and 11% lower in the first year of the study in rotted and stockpiled manure,

[3] NR- not recorded

respectively, compared to the fertilized plots. However, by the fourth year of the study, continuous maize grain yields on the manured plots yielded higher than the fertilized plots by 3% and 4% in rotted and stockpiled manure, respectively. They suggested that this could be explained by nutrient buildup in the soil and improvements in soil water-holding capacity. Corn grain production was most economical and environmentally sustainable when manure was applied in combination with a legume rotation.

Vitosh *et al.* (1997) also determined that when nutrient rates are properly balanced, comparable corn silage and grain yields can be obtained with either commercial fertilizer or manure. Solid beef manure was applied at three different rates, 22, 45, and 67 Mg/ha, respectively, in combination with a starter fertilizer of N-P-K at 11-20-37 kg/ha. The two commercial fertilizer treatments received N-P-K at 179-20-37, and 179-94-177 kg/ha, respectively. The researchers determined that 45 Mg/ha of manure was optimum for grain and silage production. After 20 annual applications of manure, soil C in the manured plots was significantly higher than the non-manured plots, with average values of 2.4 and 7.8 g/kg, respectively. The overall accumulation of soil C was lower in silage plots than in grain plots. Soil C:N ratio was not significantly affected by any of the treatments. Soil accumulations of nutrients and salts for both manure and fertilizer were greater under the grain system than silage, and should be managed accordingly. Excessive applications of nutrients, whether they come from manure or fertilizer have detrimental effects on the soil environment as well as the growing crop.

In summary, field crop yields in a variety of soil types were positively or neutrally affected by cattle manure additions. The literature indicates that there is an economically efficient level of manure application. Beyond a particular point, increased manure application rates do not improve yields.

### 2.1.2 Poultry manure as a soil amendment

#### 2.1.2.1 Soil bulk density

Like cattle manure, additions of poultry manure as a soil amendment have been found to decrease soil bulk density (Brye *et al.* 2004; Martens and Frankenberger 1992; Weil and Kroontje 1979) (Table 9).

Table 9 - Effect of poultry manure on soil characteristics.

| Reference | Martens and Frankenberger (1992) | Weil and Kroontje (1979) | Brye *et al.* (2004) |
|---|---|---|---|
| Location of study (yrs of study) | California (25 mo) | Virginia (5) | Arkansas (4-6 wks) |
| Soil type | Arlington coarse-loam | Davidson clay loam | Dewitt silt loam, Calhoun silt loam, Sharkey silt loam |
| Manure quantity applied (Mg/ha/yr) | 0, 75 | 0, 27, 57, 85, 110 | 0-6.25 |
| | **Soil characteristic† (% change over control)** | | |
| **Bulk density** | Decreased (7) | Decreased (37) | Decreased (4‡) |
| Aggregate Stability | Increased (22) | Increased (21) | |
| Moisture Content | Increased (3) | | Neutral |
| Infiltration | Increased (18) | Increased (471*) | |

† A blank in the table indicates that the characteristic was not considered by the authors.
‡ Decreased only in the Dewitt silt loam.
* The increase noted in the fall.

Martens and Frankenberger (1992) compared the effects of poultry manure, sewage biosolids, barley straw, and alfalfa additions to an Arlington coarse-loamy soil in California. The amendments were applied at 75 Mg/ha/yr. The plots were irrigated weekly. During the 25 month study, three manure applications were made in April 1987, February 1988, and October 1988. They determined that the organic amendments decreased bulk density (7-11%), increased organic C content (13-84%), respiration rates (139-290%), and soil saccharide content (25-41%) (see Table 10).

Weil and Kroontje (1979) applied poultry manure to field plots in the spring and fall over five years at application rates of 27, 54, 85, and 110 Mg/ha. Fall applications were plowed under to a depth of 20 cm, while spring applications were disked in to a depth of 10 cm just before planting. The soil was a Davidson clay loam in Virginia. Plots were planted to corn each year of the experiment. Manure additions had a consistent and statistically significant effect on bulk density. Increasing the amount of manure decreased bulk density as much as 37% over the non-manured control.

Brye *et al.* (2004) observed the short term (4-6 wks) effects of fresh and pelletized poultry manure application in the rice-growing region of the Mississippi River Delta in eastern Arkansas. It was applied at six rates equivalent to 0, 34, 67, 134, 202, and 269 kg N/ha (about the equivalent of 0-6.25 Mg/ha/yr). Three fine-textured soils were studied: a DeWitt silt loam, a Calhoun silt loam, and a Sharkey silty clay. In the DeWitt silt-loam, higher rates of application resulted in lower bulk densities, regardless of manure form. Bulk density decreased from 1.34 g/cm$^3$ in the control to 1.28 g/cm$^3$ at the highest rate of application (decrease of 4%). This site also showed significantly higher early season stand development at the higher manure rates compared to the control. This suggests that the short-term effects of poultry manure on bulk density could lead to a near-surface soil environment with less resistance for seedling emergence. The authors suggested that this could lead to improved yields for all major agronomic crops grown in the region, including rice, soybean, wheat, cotton, corn, and grain sorghum. Little effect was noted in the other soil types tested.

Table 10 - Effect of various organic amendments on various soil and soil-water characteristics

| Parameter | Effect of amendment | Amendments | | | |
|---|---|---|---|---|---|
| | | Poultry | Sewage | Straw | Alfalfa |
| | | ----% change compared to control--- | | | |
| Organic C content | Increase | 57 | 84 | 37 | 13 |
| Bulk density | Decrease | 7 | 10 | 11 | 7 |
| Soil respiration rates | Increase | 140 | 198 | 290 | 180 |
| Soil aggregate stability | Increase | 22 | 24 | 59 | 40 |
| Soil saccharide content | Increase | 37 | 31 | 41 | 25 |
| Soil moisture content | Increase | 3 | 9 | 25 | 4 |
| Cumulative water infiltration rates | Increase | 18 | 39 | 52 | 50 |

(adapted from Martens and Frankenberger 1992).

In summary, poultry manure can decrease soil bulk density in coarse- and fine-textured soils. Short-term improvements in soil bulk density may improve conditions for seedling emergence, which could lead to improved yields in a variety of crops.

#### 2.1.2.2 Soil-water characteristics and aggregate stability

Martens and Frankenberger (1992) found that additions of poultry manure to soil resulted in significantly increased (18%) cumulative water infiltration rates compared to the control. Other organic amendments further increased water infiltration rates (see Table 9). The authors thought the observed dramatic increase in water infiltration rates of all organic amendments could be due to increased aggregate stability (22-59%) and soil moisture content (3-25%) (Table 9). They recommended that regular organic additions be incorporated into management plans to enhance water infiltration rates in the soil.

Weil and Kroontje (1979) found that aggregate stability increased from 73 to nearly 94% as poultry manure rates increased from 27 to 110 Mg/ha. Their data also suggest that the effects of poultry manure on surface water infiltration can be very complex. The data showed that water infiltration rates in the spring were the slowest in the plots that received the highest rates of manure. However, by November of the same year, water infiltration rates were highest where the most manure had been applied (Table 9). This appeared to be due to a water-resistant layer of manure (2.5 to 5 cm thick) at the bottom of the plow layer, 20 cm into the soil. By the end of the season, this layer of manure was much less intact as it had been decomposed by earthworm activity. The authors recommended using incorporation techniques in the fall other than plowing.

Brye *et al.* (2004) found that soil water content was generally unaffected by poultry manure application rates but results indicated that application rates may have a greater effect in soil when the moisture content is relatively low (Table 9). They also suggested that long-term field studies are needed to evaluate the effects of repeated poultry manure applications on soil physical properties and water-holding capacities of fine-textured soils.

In summary, poultry manure may lead to improved water infiltration, soil moisture content and aggregate stability. Further study is required to determine the effect of poultry manure additions on soil-water content in fine-textured soils.

#### 2.1.2.3 Yield

No information was found relating the effects of poultry manure (as a soil amendment) on crop yield.

### 2.1.3 Swine manure as a soil amendment

#### 2.1.3.1 Soil bulk density

*Included in the next section.*

#### 2.1.3.2 Soil-water characteristics and aggregate stability

There is very little information in the literature relating the impact of swine manure applications on soil bulk density, soil-water characteristics, or aggregate stability. Choudhary *et al.* (1996) also found little to no information about the effect of swine manure on these characteristics in their global literature review of the use of swine manure in crop production. Their emphasis was on crop yield and soil and water quality.

Though Choudhary *et al.* (1996) suggest that the effects of swine manure on soil quality may be similar to those reported for beef manure, Ndayegamiye and Côté (1988) found that there was a difference. They compared the effects of liquid swine manure (dry matter 3.2%, C:N ratio 5.8:1) and solid cattle manure (dry matter 19.6%, C:N 20.5:1) applications to a control. They focused on the chemical and biological properties of an acidic Neubois silty loam soil planted to silage corn over an 11 year period. Swine manure was applied annually in the spring. Cattle manure was applied every two years in the fall, and was incorporated. No inorganic fertilizer was applied. The results of the study did not show any significant change of soil pH, total N and C:N ratio in either manured soils compared to the non-manured. However, organic C, CEC, microbial activity and potentially mineralizable N were increased more significantly by the cattle manure than the swine manure in all cases. If swine manure is applied with crops that have a high return of organic residue, ie. corn leave about 600-1000 kg/ha/yr of stable humus, it is likely that the corn residues can maintain an optimal level of organic matter. However, they recommended that swine manure not be applied to rotations with low returns of organic residues, ie. potatoes, particularly on soils of low OM content. The nutrients in the swine manure improve soil microbial activity which stimulates decomposition of the native OM, without replacing it.

Schoenau *et al.* (2005) also compared the effects of cattle and swine manure on soil quality. Both liquid swine and solid cattle manure were applied over an 8 year period to a loamy Black Chernozemic soil planted to a canola, wheat, barley rotation in Saskatchewan. The rotation was interrupted in year 5 with one year of flax seed being planted. Swine manure was applied by injection at rates of 0, 38, 75, and 150 Mg/ha/yr and cattle manure was surface applied at rates of 0, 7.6, 15.2, 30.4 Mg/ha/yr. They reported that increases in soil OC from liquid swine manure additions are minimal compared to the effects of cattle manure additions. They also noted that because the nutrients in the swine manure will stimulate microbial activity and enhance decomposition without adding more OC, there may be a counteracting effect and it may take several years before significant increases in soil OC are observed.

At the same site, Assefa *et al. (*2004) found that while aggregate stability increased from 0.75 to 0.84 where cattle manure had been added, no significant changes to aggregate stability were noted where swine manure had been added. Swine manure additions did decrease soil bulk density over the control (1.34 $Mg/m^3$) by as much as 8%.

#### 2.1.3.3 Yield

The review by Choudhary *et al.* (1996) determined that swine manure application resulted in similar or higher crop and pasture yields than inorganic fertilizers (Appendix B). Increasing the rate of swine manure application increased crop yields but yields varied depending on actual rate and method of application, type of soil and growing conditions.

### 2.1.4 Other manures as a soil amendment

There is very little information in the literature where research was carried out on how other manure types, including horse, sheep, mink, rabbit, etc. affected soil physical properties.

### 2.1.5 Anaerobically digested sewage biosolids as a soil amendment

#### 2.1.5.1 Soil bulk density

Similar to manure, anaerobically digested sewage biosolids, as a source of OM, would be expected to affect bulk density. Grupta *et al.* (1977), Kladivko and Nelson (1979) and Lindsay and Logan (1998) found that increased rates of anaerobically digested sewage biosolids resulted in decreased bulk density (Table 11). Grupta *et al.* (1977) applied the biosolids at 0, 112, 225, 450, and 900 Mg/ha onto a Hubbard coarse sand in Minnesota during the growing seasons of 1972 and 1973. They found that bulk density decreased as much as 28% under the highest rate (900 Mg/ha) of biosolids application.

Kladivko and Nelson (1979) conducted a one-year study on three Indiana soil types, a Celina silt loam, a Blount silt loam, and a Tracy sandy loam. They applied and incorporated anaerobic sewage biosolids to these soils at rates of 0 and 56 Mg/ha. They found bulk density to significantly decrease during the first 6 months of the study, then increase slightly. This trend was thought to be a result of the loosening effect of earthworms, insects and roots during the growing season. Over the winter, processes such as frost heave and settling (after thawing) can also increase bulk density.

Lindsay and Logan (1998) applied sewage biosolids in the fall of year one at the rates of 0, 7.5, 15, 30, 60, 90, 120, 150, 188, 225, 300 Mg/ha to a Miamian silt loam in Ohio. They found that decreases in bulk density were significant even four years after the application of biosolids.

All three studies (Grupta *et al.* 1977; Kladivko and Nelson 1979; Lindsay and Logan 1998) found that there was a linear relationship between biosolids application rates and soil OM.

In summary, sewage biosolids decreased soil bulk density when applied to coarse and medium textured soils at a variety of different application rates.

#### 2.1.5.2 Soil-water characteristics and aggregate stability

Soil-water characteristics were also affected by additions of anaerobically digested sewage biosolids (Table 11). Grupta *et al.* (1977) linked the increasing water retention of the soil at all pressures (0.1 and 15 bar) to the sorptive capacity of the OM fraction of the soil. Saturated hydraulic conductivity increased with increasing rates of sewage biosolids, whereas unsaturated hydraulic conductivity decreased with increasing rates of application. As a result, there were decreased rates of soil-water evaporation. The specific heat of the soil in the Grupta *et al.* (1977) study was also affected by sewage biosolids applications and appeared to be related to the increased soil moisture content.

In their study, Kladivko and Nelson (1979) found that sewage biosolids did not significantly change water infiltration rates but that there were significant increases in 1/3-bar and 15-bar water contents, and cation exchange capacity as a result of the biosolids application. They also found there were significant increases in the size of water-stable aggregates and the volume of large pores.

There were no appreciable changes to the available water capacity in the soil because of biosolids additions in any of the aforementioned studies (Grupta *et al.* 1977; Kladivko and Nelson 1979; Lindsay and Logan 1998), and no changes to water-holding capacity in two of the studies (Grupta *et al.* 1977; Kladivko and Nelson 1979)(Table 11).

Table 11 - Effect of anaerobically digested sewage biosolids on soil characteristics.

| Reference | Kladivko and Nelson (1979) | Grupta *et al.* (1977) | Lindsay and Logan (1998) |
|---|---|---|---|
| Location of study (yrs of study) | Indiana (1) | Minnesota (2) | Ohio (4) |
| Soil type | Celina silt loam, Blount silt loam, Tracy sandy loam | Hubbard coarse sand | Miamian silt loam |
| Biosolid quantity applied (Mg/ha/yr) | 0, 56 | 0, 112, 25, 450, 900 | 0, 7.5, 15, 30, 60, 90, 120, 150, 188, 225, 300 |
| Soil characteristic† (% change over control) | | | |
| Bulk density | Decreased (11-24*) | Decreased (28‡) | Decreased (12‡) |
| Infiltration/saturated hydraulic conductivity | Neutral | Increased (NA) | Neutral |
| Water-holding capacity | Neutral | Neutral | |
| Water retention | | Increased (NA) | Increased (NA) |
| Aggregate stability | Increased (NA) | | Increased (350‡) |
| Evaporation | | Decreased (NA) | |
| Porosity | Increased (19-93) | | Increased (8‡) |
| Available water | Neutral | Neutral | Neutral |

† a blank in the table indicates that the characteristic was not considered by the authors.
‡ The decrease at the highest rate of application. Percent decreases were not given for the other rates of application.
* these were the changes 6 months after biosolids application.

In summary, similar to the affect of manure additions, sewage biosolids addition to soil has been found to improve some soil-water characteristics and aggregate stability.

#### 2.1.5.3 Yield

No information was found relating anaerobically digested sewage biosolids as a soil amendment and crop yield.

## 2.2 Manure additions and risk of crop failure

Crop failure can occur for a variety of reasons, such as disease, weather damage, drought, etc. Lotter *et al.* (2003) found that maize yields were significantly higher and thus less susceptible to drought in four out of five years in fields that had received manure, compared to those conventionally managed fields which had not received manure. The fields which had received manure were managed organically in a cropping rotation of maize-soybean-maize silage-winter wheat-hay-alfalfa. The conventional system was a five-year maize-soybean rotation. In 1999, there was a drought followed by torrential rains. During this year, both cropping systems had severe decreases in yield, but there were substantial yield differences between systems. Maize yields were 137% higher in the organic system compared to the conventional system, and soybean yields were 152% higher in the organic system compared to the conventional system. The higher maize and soybean yields of the organic systems were assumed to be due to the higher water-holding capacity of the soils in those treatments. The site was located primarily on Comly silt loam in Pennsylvania. Additionally, they found there was twice as much water infiltration capacity in soils that had received manure over five years, compared to fields managed conventionally with inorganic fertilizers.

Though no other studies were available in the literature specifically examining how manure additions can affect the risk of crop failure, other studies have shown that manure additions lead to improved water-holding capacity (Arriaga and Lowery 2003; Ma *et al.* 2003; Miller *et al.* 2002), which may indicate that crops grown on soils receiving manure will be less affected by drought conditions.

## 2.3 Manure additions and general soil ecology

An abundance of organisms live in the soil, such as fungi, bacteria, earthworms and other invertebrates, etc. These organisms play an important role in the decomposition of OM and the resulting nutrient cycling, as well as producing residues that help to bind soil particles and make stable aggregates (Hayes and Naidu 1998).

As discussed previously, manure and other organic amendments provide OM to soil. As a source of available C, OM increases the biological activity in the soil, including earthworms, invertebrates, and other microbes. In this way, these organisms can lead to increased soil porosity and binding capacity in the soil, which is related to soil-water characteristics and aggregate stability (Hayes and Naidu 1998) (see section 2.1).

### 2.3.1 Soil microbial and enzyme activity

A number of studies have found that soil microbial populations increase as a result of organic amendments, compared to soils where only inorganic fertilizers have been applied (Bulluck *et al.* 2002a; Freitas *et al.* 2003; Martyniuk and

Wagner 1978; Min *et al.* 2003). Bulluck *et al.* (2002a) conducted a study on four farms, three of which were located in Virginia and one in Maryland. They found that additions of cattle manure and hay-manure compost positively affected soil microbial activity compared to those soils which used inorganic fertilizers. Plots were either planted into a corn-tomato or melon-tomato rotation. Freitas *et al.* (2003) analyzed soil for microbial populations in terms of activity over 4 growing seasons at a field site in Saskatchewan amended with cattle and hog manure. Plots were planted to rape, spring wheat, barley, followed by rape and were on a loamy Black Chernozemic soil. They found that microbial activity in soils treated with cattle manure was higher than in soils treated with hog manure. Martyniuk and Wagner (1978) conducted a study on a Mexico silt loam in Missouri where manure had been added to the soil at 15 Mg/ha/yr since 1888. Inorganic fertilizer treatments were also established at the site in the mid-seventies. They found that though inorganic fertilizer additions to soil had a positive effect on soil microbial populations, the effect was more noticeable in soils amended with manure at a rate of 15 Mg/ha/yr. The study by Min *et al.* (2003) applied dairy manure at low and high rates (rates not otherwise described) onto alfalfa (*Medicago sativa* L.) and orchardgrass (*Dactylis glomerata* L.) forage systems over a ten year period.

Different soil microbial populations may be sensitive to the type of materials being added to the soil (Lalande *et al.* 2003; Lupwayi *et al.* 2005; Marschner *et al.* 2003). Marschner *et al.* (2003) applied organic amendments (manure, sewage biosolids, and straw) at low rates (5.2 Mg/ha/yr, 7.6 Mg/ha/yr, and 4.0 Mg/ha/yr, respectively) over a 31 yr period to a reclaimed loess soil in Germany. The organic amendments appeared to increase bacterial biomass while having no effect on fungal biomass. The changes to soil C:N ratio were highest with the addition of straw (8:1,) followed by sewage (7.5:1) and manure (7.2:1). Marschner *et al.* (2003) noted that changes in community composition were not necessarily accompanied by changes in enzymatic activities.

Lupwayi *et al.* (2005) applied cattle manure (dry matter 31.6%), hog manure (dry matter 3.7%) and inorganic fertilizer annually or triennially in field trials conducted on a low-C Gray Lucisolic soil in Alberta over three years. The trials were planted in year one to a canola (*Brassica napus* L.), in year two to barley (*Hordeum vulgare* L.), and in year three to wheat (*Triticum aestivum* L.). Compared to the control, cattle manure increased soil microbial biomass C by 26%, hog manure by 31%, and inorganic fertilizer applications decreased microbial biomass C by 20-64%. Soil bacteria diversity also increased more with cattle manure than hog manure, but both organic treatments caused a greater increase than the inorganic fertilizer. Cattle manure produced the highest grain yields (increases of 25-50%) of all the treatments.

Soil enzymes are both mediators and catalysts of important soil functions and have been used to measure the influence of natural processes and anthropogenic activities on soil quality (Kremer and Li 2003). Lalande *et al.*

(2003) found inorganic fertilizers to minimally influence microbial biomass C levels or enzymatic activities of a Bevin loamy sand. Microbial biomass C levels and enzymatic activities were very similar if papermill biosolids mixed with hog manure compost (dry matter 287 g/kg and C:N ratio of 39.8:1) was added to the soil alone or in combination with inorganic fertilizers. The biosolids-manure mixture was applied at rates of 0, 11.5, 23 and 34.5 Mg/ha. Microbial biomass C levels and enzymatic activity were highest when the biosolids-manure mixture was applied at a rate of 11.5 Mg/ha. The mean increase in microbial biomass C was 55% and the enzymatic activity was 30% higher, compared to the control where no biosolids-manure was added.

El-Shinnawi *et al.* (1988) found that soil enzymatic activity varied depending on whether or not manures had been anaerobically digested. Though the study was conducted in Egypt, the results are relevant to this study, as they relate to the effect of the digestion on manure enzyme activity. Their experiment was conducted on two soils in Egypt (clay loam and sandy soil), and manure types were: anaerobically digested mixture of maize stalks and cattle manure (AMC), anaerobically digested cattle manure (AC), composted mix of cattle manure and maize stalks (CMC), and conventional cattle manure (CM). AMG and AC were digested for various times. The manures were applied at a level equivalent to 2% C. The two marker enzymes were dehydrogenase and nitrogenase. They found that enzyme activity decreased in soil as manure anaerobic digestion time increased. This could be attributed to the fact that, as anaerobic digestion proceeds, there is a decrease in bacterial numbers and decrease or disappearance of some compounds, especially those preferred by much of the heterotrophic population for C and energy acquisition. The effect of manure types on enzyme activity showed sensitivity to soil type. Sandy soils had higher dehydrogenase and lower nitrogenase activities than the clay loam soil. Anaerobically processed manures produced higher dehydrogenase and lower nitrogenase activities in both soils than the aerobically processed manures.

Because enzymes can help to produce the substances that can facilitate aggregate stability, the study by El-Shinnawi *et al.* (1988) may be significant in terms of the role that anaerobically treated manures can play in aggregate stability. Further study is warranted in this area.

In summary, the addition of manure and sewage biosolids to soils can positively affect soil microbial populations and enzyme activity. The degree to which they are affected may vary according to organic amendment properties, and enzyme activity may be decreased when the amendments are anaerobically digested. Because microbial populations and enzyme activity can positively affect aggregate stability, many of the economic benefits related to aggregate stability, such as lower fuel costs for tillage machinery and better soil conditions for root growth can be attributed to these organisms and enzymes in the soil.

### 2.3.2 Earthworm activity

Earthworms play an important role in the turnover of organic matter in soil and in building and maintaining a good soil structure. A number of studies found that earthworm activities increased with increasing application rates of manure (Andersen 1983; Forge *et al.* 2005; Hansen and Engelstad 1999; Hayes and Naidu 1998) and sewage biosolids (Tomlin *et al.* 1993). Andersen (1983) applied high rates (50,100, 200 and 400 t annually) of farm yard manure (dry matter 25%) and slurry (6.5%, animal type not specified) to Danish test plots. They found that earthworm populations were greater on manured plots compared to the control (which received 120 kg of N), and were also greater under greater manure application rates. Andersen (1983) also noted that earthworms can affect N cycling in soil because their activities improve soil aeration and drainage, which in turn may reduce rates of anaerobic denitrification.

Forge *et al.* (2005) applied dairy manure slurry two to four times a year onto a fescue grassland for a period of six years on a medium textured soil in the Fraser Valley, BC. They applied the manure at a rate of 50 and 100 kg $NH_4$-N/ha. Their results show an increased abundance of earthworms, bacterivorous protozoa, nematodes, and fungivorous nematodes in manure-treated soils compared to both inorganically fertilized and untreated soils. This is indicative of enhanced microbial turnover and flux of nutrients through the soil food web. Application of manure for one year to previously non-treated or inorganic fertilized soil raised the abundance of such organisms to levels comparable to continuously manured soil, but the effect was not noticed until the year after application. The microbial biomass-N pool was approximately three times greater in manure-treated soil than in the control and fertilized soils.

Hansen and Engelstad (1999) found that manured soils had higher earthworm populations than soils receiving only N fertilizers on a sandy loam soil in Norway. Over the 10 years of study, earthworm populations were high regardless of whether the cattle manure had been aerated or diluted. They noted that earthworm populations were sensitive to the acidity of soils. For example, applying N fertilizer to a light sandy loam soil had an acidifying effect on the soil, and there was a corresponding decline in earthworm populations. Similar declines did not occur in the manured soils. Over application of manure slurries can also negatively impact worm populations. The authors note that inorganic N fertilizer can also have a positive effect in the long-term on earthworm populations, likely as a result of increased plant growth and, thus, more organic material added to the soil.

Tomlin *et al.* (1993) applied sewage biosolids precipitated by three chemical treatment processes (aluminum sulphate, ferric chloride and calcium hydroxide) onto a silt loam soil at four different rates (equivalent to 0, 200, 400 800, and 1600 kg Total N/ha/yr) near Guelph, Ontario from 1973 to 1980. The plots were planted to bromegrass (*Bromus inermis)* and mown twice annually. In 1989 and 1990, soil was examined for earthworm. Earthworm biomass was higher in all biosolids treatments compared to the control.

Soil compaction from liquid manure tanker traffic is a concern due to the substantial axle loads on the soils from the loaded equipment (Culley and Patni 1987). Hansen and Engelstad (1999) found that tractor traffic strongly affected earthworm population density. An average of 500 earthworms/$m^2$ was found in soil under low tractor traffic while only 180 earthworms/$m^2$ were found in areas with normal tractor traffic. Two tractor passes were done in the "low" treatment, while there were five done on the "normal" treatment. When tractor traffic is removed, Hansen and Engelstad (1999) suggest that earthworm populations seem to recover quite quickly.

In their review, Hayes and Naidu (1998) determined that increased earthworm activity can also affect water infiltration rates. When there is increased earthworm activity in the spring and summer, autumn water infiltration rates have been found to increase due to the formation of large numbers of surface-connected burrows.

In summary, manure and biosolids additions can positively affect earthworm populations. Earthworm activity has been shown to be negatively impacted by machinery traffic, but earthworm activity has also been shown to recover when the traffic is removed. When manure is applied at very high rates, manure may be toxic to earthworms.

### 2.4 Manure additions and weed seed spread and survival

One of the hesitations farmers may have about applying manures to their field may be related to the idea that manure additions lead to increased weed density in the crop.

Weed seeds are usually introduced into the animal cycle mixed in with corn feed (Larney and Blackshaw 2003). Due to differences in digestive processes, weed seed viability and survival in manure is dependant upon animal type. Harmon and Keim (1934) found that chickens were the most efficient destroyers of weed seeds (only 2 out of 1000 seeds survived), followed by sheep, horses, hogs and calves, with 64, 87, 88, and 96 viable seeds surviving out of 1000. The weed seeds species, including velvet weed (*Abutilon abutilon* L. Rusby), field bindweed (*Convolvulus arvensis* L.), cocklebur (*Xanthium commune* Britton), and white sweet clover (*Melilotus alba* Desv.), had variable rates of survival amongst the different animals.

Eghball and Power (1999) suggest that weed populations in fields receiving manures are not so much a function of the weed seeds being introduced from the manures, but rather a function of the increased nutrients made available to any germinating seed, weed or crop. The researchers applied solid beef feedlot manure, compost and inorganic fertilizer to meet crop requirements in a four year study on a Sharpsburg silty clay loam planted to corn. When nutrient application rates were similar between manure, compost and fertilizer treatments, similar weed biomass production at harvest time in three of the four years was observed.

Rasmussen (2002) found that weed populations were affected by liquid manure application method. The study was established on two sites in Denmark. The first site, a coarse sandy loam, was monitored in the first two years of the study, and the second site, a sandy loam soil, was monitored in the third and final year of the study. Sites were planted to barley and oats. Liquid swine manure was applied in the first year of study, cow manure in the second year, and mixed degassed manure in the third year. All liquid manure was applied in the spring, one to three days after seed-bed preparation. Manure was injected to a depth of 8-10 cm, and lightly incorporated after the surface treatment. Manure was applied at between 10 and 40 Mg/ha. The injection method resulted in lower weed densities compared to surface application. This was attributed to the competitive advantage of the crop over the weeds, as seen by the diminishing biomass of the weeds where manure had been injected. Barley, which has an earlier emergence time than oats, seemed to have a competitive advantage over the weeds. Weather and time of planting also influenced crop-weed competition and the relative timing of emergence and early growth of competitors. Crop yield in injected manure plots was superior to the plots receiving manure by surface application.

Manure as a composted mulch has been shown by Mathews *et al.* (2002) to control weeds. Mulch (poultry manure mixed with wood chips and actively composted for six weeks before application) applied 8 cm thick to the base of Golden Supreme apple trees in their first year of establishment in West Virginia, resulted in better weed protection and lower average soil temperatures compared to conventional herbicides or hand weeding, and higher soil moisture compared to hand weeding. Tree growth during the first year in the compost mulch was equivalent to or better than that in conventional herbicides and hand weeding. Trunk diameter for apple trees was positively correlated with future fruit yields, suggesting that the trees receiving the compost mulch should have an advantage in terms of potential production. In addition, the abundance of detritivores in the mulch could aid in predator stabilization by providing an alternative food source for predators. Mathews *et al.* (2002) also monitored for changes in soil (edaphic) and arboreal arthropods, as well as substrate microclimate. The results of the study by Larney and Blackshaw (2003) indicated that weed seed viability in feedlot cattle manure can be reduced through composting.

In summary, manure additions may have a neutral effect on weed biomass compared to fertilizer treatments, though studies available for review were minimal. Surface application of manure may favour weed biomass compared to manure injection methods. Manure mulch has also been shown to control weeds in apple seedling nurseries.

## 2.5 Manure additions and plant pathogen control

Not all soil organisms are beneficial to crop growth. Some soil organisms (e.g. parasites, fungi or bacteria) are pathogenic to crops. Since their introduction onto the commercial market, pesticides have been used to try to protect crops from pathogens. The criticism of such practices is that applications of pesticides kill both unwanted and useful soil organisms. A variety of producers, especially horticultural producers, employ integrated pest management (IPM) techniques to try to maximize pest control without reducing the amount of beneficial organisms in the soil. Generally speaking, the benefits of applying organic amendments for disease control are incremental. That is, organic amendments are generally slower acting than chemical fumigants or fungicides, but may also last longer and their effects may be cumulative (Bailey and Lazarovits 2003).

Most of the scientific research published to date examining the soil pathogen control potential of manures has been done at Agriculture Canada and has focused on the effect of manure applications to potato pathogens (Bailey and Lazarovits 2003; Conn and Lazarovits 1999; Conn *et al.* 2005; Tenuta and Lazarovits 2004). Verticillium wilt, (*Verticillium dahliae* Kleb.) a soilborne fungus in association with various nematode species, and potato scab (*Streptomyces spp.*), a bacteria, are two of the more important diseases of potatoes in Ontario and worldwide.

Conn and Lazarovits (1999) applied poultry manure (66 Mg/ha), liquid swine manure (55 hL/ha), and cattle manure (100 Mg/ha) to two sandy loam sites, one near Alliston Ontario, the other near Everett Ontario. The manures were only applied in the first year of the three year study. The poultry and swine manures significantly reduced the incidence of verticilium wilt, potato scab, and populations of plant parasitic nematode populations at the sites while applications of cattle manure (100 Mg/ha) were found to have a mainly neutral effect on these parasitic populations.

Conn and Lazarovits (1999) note that even though chicken manure application was highly effective in reducing the incidence of all three parasitic populations in the first year at both sites, scab incidence on tubers at the Alliston site increased to twice that of the not treated control by the end of the third year of the study, while at the Everett site, reduced levels of nematodes were seen for two years after application and reduced potato wilt levels were seen for three years after manure application. The complexity of the results of this study highlights that the impact of manure on disease control cannot yet be easily predicted.

Bailey and Lazarovits (2003) suggest that there is considerable evidence to support the view that it is ammonia ($NH_3$) and/or nitrous acid ($HNO_2$) liberation following application of high-N amendments that is responsible for killing soil pathogens, but that results can be variable. Some of the variability has been shown to be dependant on soil texture. After incubating twelve soils of variable soil properties amended with bone meal biosolids for 29 days, Bailey and Lazarovits (2003) found that the effectiveness of the biosolid (pH 6.5 in water, 3% moisture, 38.4% organic C, and 7.7% organic N) to kill the Microsclerotia (MS) of the soil borne plant pathogen *V. dahliae* was dependent upon the ability of soil to accumulate and sustain high concentrations of $NH_3$ or $HNO_2$. The toxicity of ammonia to MS was linked to soils with low organic C (<1.4%) and high sand content (>70%). Nitrous acid toxicity was linked to soils with an acidic pH and rapid rates of nitrification.

MS fatality in soils has also been linked to the presence of volatile fatty acids (VFAs) in manures (Conn *et al.* 2005). About 65% of manures have enough VFAs to be potentially pathogen suppressing. Further, VFAs ($pK_a$ 4.75) are only active at low pH (Conn *et al.* 2005). The relationship between MS toxicity of VFAs and other factors such as VFA concentration in manure, soil pH, buffering capacity, moisture content and temperature, is not well understood and warrants further research (Conn *et al.* 2005).

Application of pig slurry to soils has also been shown to negatively affect the survival of *Ralstonia solanacearum* strain 1609, another soil pathogen linked to a wilting disease in potatoes, especially when combined with soil solarization techniques (covering soil with plastic) (Gorissen *et al.* 2004).

The root holoparasitic organism, branched broomrape (*Orobanche ramose* L.), is a parasitic weed prevalent in potato production in Lebanon typical to alkaline soils. Studies in Lebanon by Haidar and Sidahmed (2006) and Haidar *et al.* (2003) found that goat manure and fresh chicken layer manure applied in combination with elemental sulphur can diminish the broomrape in potato and eggplant. Cattle, chicken broiler, layer and sheep manure were also applied at rates of 10, 15, and 20 Mg/ha but did not decrease broomrape infestations Though the studies may not be relevant to agriculture in Ontario at first glance, the studies do highlight the variable potential of manure types to act as a plant pathogen control.

Bulluck et al. (2002b) studied the effect of solid swine manure on nematode trophic groups under tomatoes. Two experimental sites in North Carolina, a loamy sand and a sandy loam soil were planted to tomatoes two weeks after soil amendment applications. The soil was amended with either solid swine manure (broadcast and incorporated) or inorganic fertilizers. They found manure applications increased populations of bacterivorous nematodes and bacteria, suggesting a bacteria-dominating decomposition food web. They also consistently found lower fungivorous nematode population in soils amended with inorganic fertilizers compared to manure. Plant parasitic nematodes were relatively unaffected by soil amendments. However, root-gall development was suppressed by the manure.

Manure additions to soil, particularly manures with high-N levels, seem to exhibit soil pathogen control potential of Verticillium wilt, potato scab, *R. solanacearum* 1609, branched broomrape, and some plant parasitic nematodes- all pathogens particular to potato production. However, pathogen control of manures is quite variable and needs further research before it is promoted as a viable means of controlling some crop pathogens.

## Part 2 – Environmental Considerations

## 2.6 Manure and sewage biosolids applications and impacts on water quality

### 2.6.1 Pathogen water contamination

Drinking water contaminated with manure-borne pathogens, such as *Escherichia coli*, *Cryptosporidium*, or *Salmonella*, can have devastating consequences in a human community. As such, it is imperative to understand the pathways of manure movement to sources of drinking water in order to minimize contamination. Though it is beyond the scope of this review to examine pathogen transport to surface and groundwater following manure and biosolids applications, it is an important issue to consider when assessing the value of applying manure or biosolids to soil.

Studies have been conducted examining manure pathogen contamination in tile outflow (Fleming and Bradshaw 1992; Patni *et al.* 1984; Shipitalo and Gibbs 2000a; Shipitalo and Gibbs 2000b), surface runoff (Patni 1978), and ground water (Goss *et al.* 1996). Generally speaking, the transport of manure pathogens is a complex issue, influenced by manure type, soil type, soil moisture conditions at application time, precipitation events, and tillage practices, etc. There are a variety of management techniques that can be implemented to reduce the risks of surface- and groundwater contamination by manure pathogens. Some of these techniques include: 1) following minimum distance setback guidelines for application of manure close to streams and surface waters, Hickenbottom inlets (i.e. surface inlets), and well-heads; 2) avoiding spreading manure onto frozen ground; 3) minimizing the amount of spillage that happens between the manure storage facility and the field of destination; and 4) disturbing the soil surface prior to liquid manure application onto tile drained fields. Many of these practices have been integrated into Ontario’s Nutrient Management software program, NMAN (OMAFRA 2000). NMAN has been designed to help farmers create provincially approvable nutrient management plans.

### 2.6.2 Nutrient water contamination

Nutrient transport to ground- and surface waters from soils receiving manure or sewage biosolids amendments is also an issue that is beyond the scope of this review, but of value to mention. When manure is applied at rates in excess of crop nutrient requirements, land application of manures can lead to nutrient loading to ground- or surface waters (Edmeades 2003; Hao *et al.* 2003).

Hao *et al.* (2003) reported on the effects of heavy rates of manure application over a 25 year period. After 22 years of barley (*Hordeum vulgare* L.), in 1996, the non-irrigated blocks were planted to canola (*Brassica napus* L.), back to barley in 1997, and finally to a tritcale (*Triticoscale* L.) in 1998. A similar cropping was done on the irrigated sites, except that corn (*Zea mays* L.) was planted in 1997 and 1998. Very little residue was left on the soil at harvest time for all years. Manure was applied at 0, 30, 60, 90 Mg/ha on non-irrigated land, and at 0, 60, 120, 180 Mg/ha on irrigated land. Hao *et al.* (2003) found the soil organic C and total N levels accumulated over 25 years of application, with more accumulation occurring where more manure was applied. The distribution of soil organic C and total N in the soil profile decreased with decreasing depth and increased linearly with increasing rates of manure. Organic C and total N levels were as high as 45.7 and 4.86 g/kg for the non-irrigated plots, respectively. In the control, organic C and total N levels were 19.0 and 2.16 g/kg, respectively. In the irrigated plots, organic C and total N levels were as high as 76.1 and 7.83 g/kg, respectively, compared to 19.0 and 2.11 g/kg in the control. Ammonium-N levels were not significantly affected by the rate of manure application. Nitrate-N levels increased with increasing rates of manure, more markedly in non-irrigated conditions compared to irrigated conditions. The authors note that these high levels of $NO_3$ could represent a potential risk of pollution to surface and ground water because $NO_3$ is very mobile in soils.

In a review completed in association with the Fertilizer Information Services Ltd of New Zealand, Edmeades (2003) found that soils receiving long term applications of manures could result in soils becoming excessively enriched with some nutrients, particularly P, K, Ca and Mg in the top soil, and with nitrate-N, Ca and Mg in the subsoil. Though the accumulation of K, Ca, and Mg will not likely pose an environmental risk, accumulation of P and N in the soils can lead to P and N enrichment in runoff and leachate. Similar results were found by Whalen and Chang (2002). Applying manure and sewage biosolids to meet agronomic requirements of P and supplementing N requirements with inorganic fertilizer has been proposed as a strategy to minimize nutrient enrichment of soils (Eghball 2002; Whalen *et al.* 2001).

In summary, application of manure at crop nutrient requirement rates can minimize the risks of nutrient movement to surface and ground waters. Limiting manure application rates to nutrient requirements may mean that improvements in soil quality improvements may take longer to develop.

### 2.6.3 Soil erosion

As soil aggregate stability improves, soil is less likely to be dislodged by a raindrop where it would be more likely to be lost in runoff (Benbi *et al.* 1998). Since soil aggregate stability can be improved with additions of beef cattle manure (Loveland and Webb 2003; Munkholm *et al.* 2002), dairy manure (Min *et al.* 2003), poultry manure (Martens and Frankenberger 1992; Weil and Kroontje 1979) and sewage biosolids (Kladivko and Nelson 1979; Lindsay and Logan 1998; Martens and Frankenberger 1992) (section 2.1), it is not surprising that manure application can lead to reductions in soil erosion (Gilley and Risse 2000). Gilley and Risse (2000) found soil loss reductions of 15 to 65% on lands receiving annual application of manure at soil conservation experimental stations across the US (Missouri, Iowa, Wisconsin, New Jersey, Minnesota, Idaho, and Pennsylvania). Reductions in soil erosion may lead to decreased sedimentation in streams, and thus reduce negative impacts on stream wildlife and stream flow capacity.

Soil erosion is also influenced by the runoff potential of soils. If soil runoff can be reduced, it is possible to reduce soil erosion rates. Gilley and Risse (2000) found that manure additions reduced water runoff from manured soils by 2 to 62%. This may be linked to the fact that manure and biosolids applications can lead to increases in water infiltration rates under saturated conditions (Araji *et al.* 2001; Benbi *et al.* 1998; Miller *et al.* 2002), and improved water retention (Grupta *et al.* 1977; Lindsay and Logan 1998).

The study by Unc and Goss (2006) suggested that the capacity of manures to reduce surface runoff may also be related to manure properties. They found that soils that had received liquid swine manure showed higher rates of surface water runoff after the application compared to soils that had received solid manure additions. This was because the smaller surface pores became blocked more efficiently after addition of liquid manure thereby limiting soil's hydraulic conductivity.

Improvements in water infiltration and soil water capacity, particularly in saturated conditions, is significant in terms of stream water hydrology. During high volume rainfall events, if water can be more easily infiltrated into a field, and if that field has increased water-holding capacity, stream water peak flow may be delayed and drawn out over a longer period of time. This can reduce the risk of stream bank erosion, or loss of newly- planted seeds near a stream bank. These translate into positive economic value to both the farmer and society.

Reductions of soil loss and surface runoff can also mean lowered risk of the transfer of soil borne nutrients and pathogens, such as phosphorus and *Cryptosporidium*, to surface waters. Additionally, top soil is the most fertile fraction of the soil. When top soil is lost in surface runoff over a period of time, it can lead to reduced soil fertility and structure, which would have a negative impact on crop production. Each of these aspects also translates into positive economic value to both farmer and society.

In summary, the positive effects of manure on soil quality (improved aggregate stability, improved water-holding capacity, and improved saturated hydraulic conductivity) can reduce soil erosion rates, reduce stream peak flows, and reduce overland flow of potentially contaminated water.

## 2.7 Manure applications and food safety

The application of manures to horticultural crops poses a risk to human health that does not exist in field crops because trace amounts of manure and pathogens may be present on the surface of the fruit or vegetable meant for immediate and raw human consumption. To minimize this type of risk, manure applications less than 120 days before harvest is not recommended (OMAFRA 2006).

Natvig *et al.* (2002) found that *E. coli* and *S. enterica* survival rates on root and leaf vegetables grown in soils with incorporated beef manure was low as long as the manure was applied in early spring or late fall and at least 120 days between manuring and harvest. However, *S. enterica* survival may be more likely if manure is applied in early summer for a fall harvest, even if more than 120 days elapses. They also found that contamination of leaf and root vegetables by manure-borne bacteria is more likely in silty clay loam compared to loamy sand, probably because the higher clay content of silty clay loam soil resulted in visibly greater adherence of potentially contaminated soil to vegetables. The experiment was conducted in two controlled-environment chambers. Temperatures in the chambers corresponded to temperatures typical to Wisconsin between March (around $0^{o}C$) and October ($13^{o}C$), with summertime temperatures of about $25^{o}C$.

Côté and Quessy (2005) looked at the survival of *E. coli* and *Salmonella* in pickling cucumber (*Cucumis sativus* L.) production. They applied liquid swine manure at 115 and 80 kg N/ha to a Lachute loamy sand, a St. Damasse sandy loam, and two Soulange sandy loams over three different years. The quantity of swine manure was 94 and 37 $m^3$/ha for the 115 kg N/ha treatment, and 65, 25, and 27 $m^3$/ha for the 80 kg N/ha treatment (the 115 treatment was not measured in the 3$^{rd}$ year). The overall number of days required to reach undetectable concentrations of *E. coli* in a sandy loam soil ranged from 37 to 97 days and in the loamy sand was 50 to 124 days. No pathogens were detected on the harvested cucumbers. They conclude that a delay of 100 days between manure application and harvest appears to be a safe management practice for a sandy loam, but that more research is needed to determine a safe delay for other soil types. Temperatures were typical for the region (near Montreal, Quebec), with daytime highs fluctuating from the high teens to low 30s (degrees Celsius) between June and September.

Hutchison *et al.* (2004) suggested that survival of manure-borne pathogens is decreased when manure is left on the soil surface, compared to incorporation of manure, but cautioned that leaving manure on the soil surface may create other problems, such as transport of pathogens to surface waters and pathogen infection of birds and rodents.

In summary, pathogen contamination of fruit and vegetable crops after manure application can be minimized by allowing for a period of time to pass between application and harvest. Pathogen survival is influenced by soil type, with indications that survival may be longer in finer-textured soils.

### 2.8 Manure applications and odour levels

For some, the greatest negative impact of manure application to soil is the associated odour of the practice. In fact, manure odour is often the number one cause of complaints received by Ontario farmers (OMAFRA 2005). Schiffman and Williams (2005) looked at the science of odour associated with large livestock operations. Malodors emitted from large animal production facilities and wastewater treatment plants, for example, elicit complaints of eye, nose, and throat irritation, headache, nausea, diarrhea, hoarseness, sore throat, cough, chest tightness, nasal congestion, palpitations, shortness of breath, stress, drowsiness, and alterations in mood. The bad-smelling odours associated with large livestock operations are generally from a mixture of volatile organic compounds, hydrogen sulfide, ammonia, and particulates (including bio-aerosols) that arise during microbial decomposition of manure. There are various ways in which odours associated with land application of manure can be managed. These include: incorporation of manure within 24 hours of application, particularly when manure is applied within ~300 m of residences; minimize the number of times any one field receives manure in one year; and avoid applying manure on weekends, holidays, or the days leading up to them (OP ca 2004).

## 3.0 Recommendations of other jurisdictions related to the non-nutrient value of manure

While the nutrient value of manure is recognized as the main benefit of manure applications, other jurisdictions also recognize its non-nutrient value. This is mainly through contributions to soil organic matter - however, this benefit is often only briefly mentioned (Brandjes *et al.* 1996; Johnson and Eckert 1995; Magdoff and van Es 2000; ManAgr 2001; Nyiraneza and Snapp 2003; PEI 1999; Prairie 2006; Rosen and Bierman 2005; Snapp *et al.* 2003; Sutton and Joern 1992; USDA 1995).

Organic matter from manure applications which remains after one year is considered part of the soil organic matter (stable organic matter or humus). It is not surprising that the non-nutrient benefits of manure identified are similar to those identified in the scientific literature (i.e. improved soil structure, reduced erosion and compaction, and increases in water holding capacity (Brandjes *et al.* 1996). Additions of livestock manures to the soil can provide a relatively high contribution to the soil organic matter (high humus coefficient) (Brandjes *et al.* 1996), which is especially significant in cropping systems which return only small amounts of crop residue to the soil (Nyiraneza and Snapp 2003; Rosen and Bierman 2005). Manures are especially useful at improving the soil physical properties of degraded soils (AAFRD 2004) or soils naturally low in organic matter (BCAGF 2005). Long term studies of manure application suggest that manures increase water infiltration rates into larger pores but decrease infiltration into smaller pores (AAFC 2000).

Manure applications have been associated with improved yields of low residue vegetable crops in Michigan (Snapp *et al.* 2003). This may be due to an increased nutrient supply as well as enhanced soil microbial activity and increases in soil OM (Snapp *et al.* 2003). It is recognized that contributions to soil organic matter depend on the type of manure and application rate (OMAFRA 2002), the climate, and the production system (Brandjes *et al.* 1996). Magdoff and van Es (2000) suggest 45 to 67 Mg/ha of solid dairy manure are required to maintain soil organic matter if a low residue crop is grown. Brandjes *et al.* (1996) suggest that 4.8 Mg/ha of manure are required in rice production to maintain soil organic matter. Application rates should increase to over 18 Mg/ha on non-irrigated land in lowland tropics due to increased soil organic matter decomposition. Manure nutrient analysis should always be determined before application and rates should not exceed crop nutrient requirements (BCAGF 2004).

Manure applications to farm land have also been characterized in terms of their environmental benefits. Koelsch (2006) suggests that the environmental benefits of manure applications are reductions in the demand for commercial phosphorous fertilizers, reductions in the energy demand for natural gas intensive nitrogen fertilizers, and reductions in atmospheric carbon levels. Carbon sequestering in the soil is a way to make up for greenhouse gas emissions (OMAFRA 2003).

The monetary value of manure is often based on its nutrient content (Ohio 2002) but it has been suggested that its impact on soil organic matter and the associated soil quality improvements (improved soil structure, increased activity and diversity of soil organisms) doubles the value of manure (Magdoff and van Es 2000). This rather arbitrary monetary assessment of manure's non-nutrient value could not be substantiated by any scientific literature.

Heavy applications of manures have been associated with increased soil borne diseases in potatoes; however, recent research has suggested that applications of composted poultry manure, swine manure, and paper mill residue can suppress soil borne diseases in snap beans, cucumbers and potatoes in some cases (Snapp *et al.* 2003).

In summary, the recommendations of other jurisdictions related to the non-nutrient value of manure application to farm land reflects the information found in the review of the scientific literature. In general, the value assigned to manure was related to its nutrient value. The non-nutrient value of the manure was considered only as a bonus.

# 4.0 Summary and recommendations

This study has confirmed that most of the research effort to establish a value for livestock manure or sewage biosolids has dealt with the “nutrient” value of the materials. These nutrient concentrations and their availability to crops have typically been compared to the nutrients in inorganic fertilizers. The review of typical crop recommendations in several nearby provinces and states backs this up. The main value of these materials is considered to be the nutrients, especially the quantities of N, P and K that are readily available. Any non-nutrient value that can be recovered is considered to be a bonus, and there has been very little attempt to assign a value to these benefits.

There have, however, been a range of studies that have looked at the non-nutrient value of manure and biosolids, even if the focus has not been to establish an economic value. The main findings of the review are summarized here.

**Agronomic Considerations**

**a) Soil physical quality**

- Applications of cattle (beef and dairy), poultry and swine manure, as well as sewage biosolids can decrease soil bulk density in a variety of soil types, cropping systems, and climates. However, based on experience with cattle manure, it appears that there will be little or no impact on bulk density when existing organic matter levels in the soils are high.
- Very little information was found on the effects of swine manure applications on soil physical quality. One study cautioned the use of liquid swine manure on crops that returned very little organic matter to the soil. The manure improves soil microbial activity, breaking down the native OM without replacing it.
- No information was found on how other manure types, such as horse, sheep, mink, rabbit, etc., may affect soil physical quality.
- No information was found comparing the relative impacts on soil physical quality of “typical” liquid manure or sewage biosolids with anaerobically digested manures or sewage biosolids.
- Soil-water characteristics generally improved with the addition of cattle, dairy and poultry manure and sewage biosolids, including:
    - neutral or increased infiltration capacity of soils;
    - neutral or increased water holding capacity of soils; and
    - decreased evaporation rates.
- Manure and biosolids additions improved aggregate stability in most cases, which may lead to:
    - Lower energy costs associated with spring tillage
    - Less risk of soil structural damage if tillage is done when soil moisture levels are high

  - Better crop seedling emergence and root development, which may positively impact crop yield.
- High rates of cattle manure application may lead to aggregate dispersion due to the high salt content of cattle manure.
- Cattle manure additions to soil can provide a liming effect, thus reducing the need for additional amounts of commercial lime inputs.
- Manure and sewage biosolids can have a neutral to positive effect on crop yields, including corn silage, grain corn and alfalfa.
- No studies were found that looked into the effects of soil quality on horticultural crop yields, where soil quality was influenced by the application of manure and sewage biosolids.

Table 12 gives a summary of the main effects of manure or biosolids additions to the soil's physical quality. Where available, numbers have been included, to demonstrate the range of magnitudes of these impacts.

Table 12 - Summary of the effects of manure and biosolids additions to soil on soil physical characteristics.

| Characteristic | Manure Type | | | Anaerobically digested biosolid |
|---|---|---|---|---|
| | Cattle | Poultry | Swine | |
| | % change over control | | | |
| Bulk density | Decrease (0-35) | Decrease (4-37) | Decrease (8) | Decrease (11-28) |
| Water retention | Increase (5-48) | | | Increase (NA) |
| Water infiltration | Increase (0-730) | Increase (18-471) | | Increase (0-NA) |
| Evaporation | Decrease (4-17) | | | Decrease (NA) |
| Water-holding capacity | | | | Neutral |
| Moisture content | | Increase (0-3) | | |
| Aggregate stability | | Increase (21-22) | Neutral | Increase (NA-350) |
| Porosity | | | | Increase (8-193) |
| Available water | | | | Neutral |

NA indicates that, where studies have indicated a change, no numerical data was present in the study.

**b) Risk of crop failure**

- Only one study could be found that specifically looked at how improved soil-water characteristics affected a crop's susceptibility to crop failure. This study showed significant yield gains in fields treated with manure over fields which had not received manure in a year where there was a drought followed by torrential rains.

**c) General soil ecology**

- The addition of manure and sewage biosolids to soils can positively affect soil microbial, enzyme, and earthworm populations. The degree to which they are affected may vary according to the properties of the manure/biosolids.
- Enzyme activity may be decreased when manure/biosolids are anaerobically digested.
- Earthworm activity has been shown to be negatively impacted by machinery traffic, but earthworm activity has also been shown to recover when the traffic is removed.
- Because microbial and earthworm populations and enzyme activity can positively affect aggregate stability, many of the economic benefits related to aggregate stability, such as lower fuel costs for tillage machinery and better soil conditions for root growth can be attributed to these organisms and enzymes in the soil.

**d) Weed seed spread and survival**

- There have only been a few studies examining the effect of manure additions to weed seed spread and survival.
- Manure and inorganic fertilizer additions have similar effects on weed biomass.
- Surface application of manure may favour weed biomass compared to manure injection.
- Manure as a mulch can control weeds in apple seedling nurseries.

**e) Control of plant pathogens**

- Manure additions to soil, especially manures with high N levels, have shown the potential for controlling soil pathogens - Verticillium wilt, potato scab, *R. solanacearum* 1609, branched broomrape, and some plant parasitic nematodes; pathogens associated with potato production.
- The ability of manure to control pathogens is quite variable.

## <u>Environmental Considerations</u>

**a) Water quality and quantity**

- There are risks of contamination to surface water and groundwater quality associated with manure and biosolids application to soils. However, these risks can be minimized using known management practices.
- The addition of manure and biosolids to soil may improve water infiltration and soil water capacity, particularly in saturated conditions, which may reduce peak flows in streams and lower the risks of any related negative impacts.

**b) Soil Loss**

- Land application of manure and biosolids can reduce soil loss from fields, which may:
    - Decrease sedimentation in streams, and thus reduce negative impacts on stream wildlife and stream flow capacity.
    - Lower the risk of transferring soil-borne nutrients and pathogens, such as phosphorus and *Cryptosporidium* to surface waters.
    - Keep fertile topsoil on the land and thus minimize soil degradation.

## Recommendations

This review of literature has identified a number of gaps in the current knowledge of the non-nutrient value of manure and biosolids.

- An effort is needed to translate the benefits described in this report into economic benefits. To date, very little effort has been devoted to placing an economic value on the non-nutrient impacts of the land application of manure and biosolids. Such value does exist and should not merely be considered as a “bonus” when applying these materials to the land. Placing an economic value on the non-nutrient benefits of manure and biosolids will involve consideration of manure type, soil characteristics, crop nutrient needs, climate and other factors.
- More studies are needed to determine, over the long term, the impact on yield for field and horticultural crops of “soil quality”, comparing the influence of organic vs inorganic nutrient sources.
- Considering the importance of organic C additions to soil physical quality, any future studies examining the effects of manure or sewage biosolids on soil quality should include details of the C:N ratio of the material, as well as soil C levels.
- Further study is needed to better quantify the effects of manure and sewage biosolids on the risk of crop failure.
- There should be further research to better quantify the conditions under which manure can control plant pathogens.
- With the growing interest in manure treatment technologies (e.g. anaerobic digestion), more effort is needed to document the value of livestock manure that has undergone some form of treatment.
- Manure and biosolids should be promoted as a resource that has value beyond its nutrient value.

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## Appendix A –

# Detailed Summary of Studies Reviewed

## Appendix B –

## Effect of swine manure on crop production, crop nutrient composition and nutrient uptake