POULTRY MANURE AND COMPOSTED YARD TRIMMINGS FOR ORGANIC VEGETABLE PRODUCTION IN DELTA, B.C.

by

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Abstract

Due to a growing poultry industry in the Fraser Valley of British Columbia, an abundance of manure is shipped to Delta, B.C. Delta farmers are concerned that large quantities of poultry manure may harm crop quality and cause nitrogen leaching losses. This study tested the effects of organic fertilizer applications on agronomic indicators of crop quality and the potential for nitrate leaching in Delta, and sought tools for predicting appropriate manure application rates.

Field trials on commercial certified organic sweet corn (*Zea mays* L. *saccarata* Sturt), green bean *(Phaseolus vulgaris* L.) and broccoli (*Brassica oleracea* var. *italica* L.) fields in Delta, B.C. tested poultry manure at rates of 10 and 20 t/ha, and composted yard trimmings and a mixture of the two materials, at rates of about 10 t/ha. Weeds in the corn and bean experiments and insect pests on broccoli were not affected by treatments. Clubroot in broccoli was suppressed by manure treatments. Diagnostic levels of crop tissue nitrogen were within the sufficiency range for corn and beans. Yields were not affected by treatments, relative to controls.

In corn and broccoli fields, the potential for nitrate leaching increased disproportionately at manure rates above 25 m^3/ha. This may be a result of application rate exceeding the maximum crop N uptake, which was 140 kg/ha for corn and 110 kg/ha for broccoli.

Available soil N in control plots (soil mineral N + crop N at harvest) was about 115 kg/ha in the corn and bean experiments, and 89 kg/ha in broccoli. Laboratory incubation experiments showed that poultry manure can mineralize 160 kg N/ha over 74 days, and that composted yard trimmings reduces the N application when mixed with manure. Composted yard trimmings alone caused N immobilization after 31 d, but not after 60 d. It is recommended that the capacity of compost and manure to contribute to soil available N be better quantified in Delta, and that rates not exceed 25 m^3/ha for crops with similar uptake patterns to those studied. Annual inputs are not necessary on fields which have a large store of soil available N due to management history.

Table of Contents

List of Tables

List of Figures

List of Appendices

Tables

Figures

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"..nitrates are not the land, nor phosphates; and the length of fiber in the cotton is not the land....the land is so much more than its analysis."

- John Steinbeck, The Grapes of Wrath, 1939

1. Introduction

1.1 The B.C. Poultry Industry

Over the past two to three decades, the poultry industry in British Columbia has become more geographically concentrated, mainly in the lower Fraser Valley from Surrey to Chilliwack (Figure 1.1). In this region, chicken production alone increased 55% from 1986 to 1996 (Fraser Basin Council 2001), while turkey production increased 142% from 1986 to 1991 and then 66% from 1991 to 1996 (Schreier *et al.* 2000).

Conservative estimates project that by 2010, the growing poultry industry in the Fraser Valley will be producing 820 000 m^3 of manure per year (Anonymous 2002), an increase of 33% over current production levels, which translates into more than 8 million kg of manure nitrogen produced per year.

Of particular environmental concern is the Abbotsford region of the Fraser Valley, where well-drained silt loam soils cover a sandy, gravelly layer (Luttmerding, 1981) protecting an unconfined aquifer. As of 1993, this region was the highest producer of manure in the Fraser Valley (Chipperfield 1994). Leaching of nitrate from manure sources into the aquifer has occurred and caused concern for public health (Vizcarra *et al.* 1997, Zebarth *et al.* 1998).

To address these concerns, the Sustainable Poultry Farming Group was established in 1990 (http://www.sustainablepoultry.ca). Among other extension activities, this group initiated the Groundwater Protection Program, which provides manure market studies and facilitates manure export from the Abbotsford region. In 1996, Delta, at the western end of the Fraser Valley, was the largest recipient of manure exported from the Abbotsford area, accepting about 50% of total exports (Chipperfield 1996). By 2000, this fraction had climbed to 61% (Anonymous 2000).

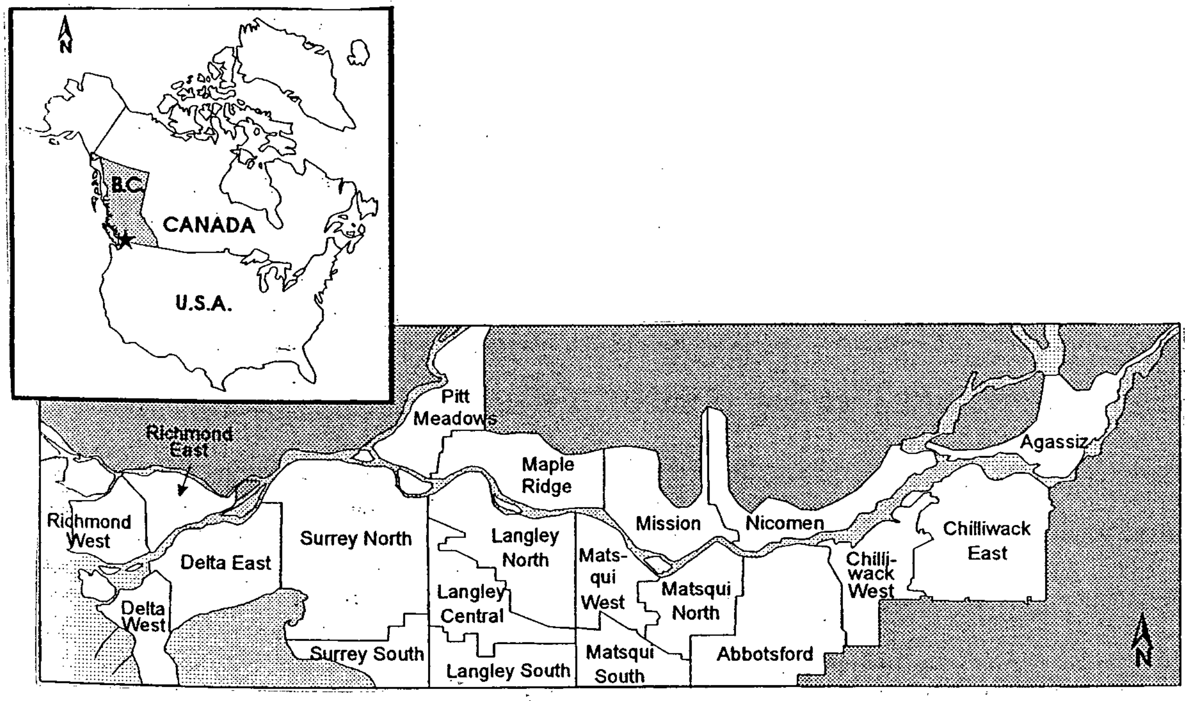

Figure 1.1 Map of the Fraser Valley, British Columbia
(from Zebarth *et al.* 1999)

1.2 Delta: Current Production Profile and Manure Application Practices

According to Klohn Leonoff Ltd. *et al.* (1992), Delta's agricultural capability ranks in the top 20% of the arable land in the province. Most cultivated soils in Delta, once appropriately drained, belong to class 2 of the land capability system. Flat topography, a long growing season and high number of sunshine hours are also environmental aspects in its favour. As of 1992, the farmed land base in Delta was 7 527 ha, 74% of the 10 184 ha of Agricultural Land Reserve contained in Delta's jurisdiction (Klohn Leonoff Ltd. *et al.* 1992).

The production profile of Delta and its proximity to the B.C. poultry industry make it an ideal market for manure. Since the 1970s, approximately half of the cultivated hectarage in Delta has shifted from mixed livestock and horticultural production to vegetable cultivation, leading to a decrease in manure nutrients in the area (Temple *et al.* 2000). Main crops are potatoes, blueberries, corn, hay and grain, with a smaller section of the land area devoted to vegetable crops such as beans, peas, cole crops and turnips (Klohn Leonoff Ltd. *et al.* 1992).

A small number of the family farmers in the region have recently converted to certified organic practices, as members of the American certification body Oregon Tilth. Organic farmers are prohibited from using synthetic fertilizers. An organic amendment such as poultry manure, which is regulated but not prohibited in organic production (Coody 1998), is an obvious alternative.

Farmers in Delta who use poultry manure commonly receive broiler litter shipments (a mixture of chicken manure and wood shavings) in the autumn, to be spread the following spring. For vegetable crops, organic farmers in Delta usually apply manure in a single application sometime in May, a few weeks before seeding. They estimate their manure application rates to be about 25 - 30 m^3/ha for most vegetable crops, including corn, beans, and potatoes and about 36 m^3/ha for broccoli. However, measurements from manure spreaders in the field have shown that rates can reach up to 55 - 60 m^3/ha on settings which are sometimes used for crops with high nitrogen demand like corn and broccoli.[1] Table 1.1 shows the conversions of volume to mass measurements and estimated nitrogen application as a result of these rates. Conversions are calculated based on an assumed fresh bulk density of 380 kg/m^3, (based on values reported by Chipperfield 1994), water content of 30%, and an estimate of 4% nitrogen on a dry weight basis for broiler litter.

Table 1.1. Nitrogen delivery by a range of possible manure application rates in Delta. (from Temple and Bomke, 2002 unpublished data)

Rate (m^3/ha)	Fresh Rate (t/ha)	Dry Rate (t/ha)	kg N/ha
25	9.5	6.65	266
30	11.4	7.98	319
36	13.68	9.58	383
55	20.9	14.63	585
60	22.8	15.96	638

In September 2000 nitrate-N levels in organic vegetable fields in Delta were found to range from 206 to 852 kg/ha.[2] In south coastal British Columbia, the risk of nitrate leaching is very high over the winter months because of the mild temperatures and rainy climate, and the mobility of the nitrate anion in mineral soils (Kowalenko 1987). Thus, soil nitrate levels in autumn are

[1] Temple, W.D. and Bomke, A.A. 2002. unpublished data.

[2] Temple, W.D. and Bomke, A.A. 2000. unpublished data., Organic and Conventional Row Crop Production: available NH_4^+-N and NO_3^--N levels.

representative of the potential contamination of groundwater by nitrate-N. These preliminary data suggest that application rates in Delta introduce excessive amounts of N into the soil.

Application rates are limited by manure spreading machinery, which dictates a minimum rate, below which the wear and tear on machinery becomes economically detrimental to farmers. This minimum rate is approximately 25 m^3/ha. For crops with low nitrogen requirements, reducing the nitrogen application by mixing a less nutrient-rich material with manure is of interest. This would dilute manure nutrients and allow farmers to apply the minimum rate.

One possible such material is municipal composted yard trimmings, available from the Vancouver Landfill, located in Delta. This material has the potential not only to dilute manure nutrients applied to the soil, but also to contribute to a buildup of soil organic matter over time. It is imperative that appropriate manure management practices are developed for Delta that preserve soil and water quality, crop quality and the relationship of farmers with their markets. This need is particularly acute for organic farmers who risk losing organic certification if they cannot demonstrate that their manure management practices are deliberate and environmentally benign. If this is not achieved, Delta farmers may begin to refuse poultry manure in favour of an alternative that does not jeopardize their markets. This would be a serious setback to the efforts of the Groundwater Protection Program, and for nutrient management in the Fraser Valley in general.

Farmers are concerned that their manure application practices are largely based on guesses, and they are interested in a science-based application scheme. To build such a scheme, the effects of current and alternative application practices on crop quality and the potential for nitrate leaching should be documented.

1.3 Objectives

The objectives of this study are:

1. To assess the impacts of poultry manure and composted yard trimmings fertilizer treatments on agronomic indicators of crop quality.

2. To assess the effects of poultry manure and composted yard trimmings fertilizer treatments on the potential for nitrate leaching.

3. To develop tools for predicting the appropriate poultry manure nitrogen application rate and/or material for spring applications.

2. Literature Review

2.1 Fertilizers and Crop Quality

2.1.1 Crop Diseases, Pests and Weeds

Suppression of soil-borne fungal diseases has been linked to high nitrogen fertilizers, both mineral and organic. In a greenhouse experiment on a 2:1 v:v soil:peat mixture, and in a field trial in north Scotland, Dixon *et al.* (1987) found that mineral nitrogen applications to broccoli seedlings reduced clubroot (*Plasmodiophora brassicae*) infection after transplanting into the field. Dixon *et al.* (1987) state that other authors have linked this response to better growth of N-fertilized plants, but this relationship was not found in their study.

In southwestern Ontario, Lazarovits and Conn (1997) showed a reduction in the soil-borne fungal pathogen *Verticillium dahliae* which causes verticillium wilt in potatoes, in three of four soils amended with chicken manure. However, efficacy can vary from site to site and with different manure handling practices. For example, a one-week composting period eliminated the disease-suppressing qualities of the chicken manure.

Site-specific soil characteristics such as texture, pH and organic matter can also alter the mechanisms by which the suppressive effects of manure fertilizers act (Lazarovits 2001). In soils with organic matter below 1.7% and pH above 8.5, the evolution of ammonia gas (NH_3) from biological degradation of manure can play a role in disease suppression. In sandy soils with little buffering capacity and little organic matter, with pH below 5.5, production of nitrous acid (HNO_2) occurs, which is extremely toxic to many soil-borne fungal and bacterial diseases. Since soils of Delta do not fit into either of these categories, it is difficult to predict the effect of manure fertilizers on soil-borne fungal diseases in this context.

Reductions in rhizoctonia root-rot *(Rhizoctonia solani)* were demonstrated in greenhouse experiments using composted grape marc and composted separated cattle manure on radishes (Gorodecki and Hadar 1990). This response is due seemed to be a result of higher soil microbial diversity, which increases competition with the pathogens.

Using organic fertilizers in this way represents a "probiotic" approach to disease control that runs counter to mainstream approaches of near-sterilization of soil for elimination of plant pathogens (Lazarovits 2001). However, it is an appropriate approach for organic producers who are not permitted to use most common biocides.

High nitrogen fertilization can cause increased pest predation of crops by making plant tissue succulent and vulnerable to attack (Mills and Jones 1979). Positive correlations of aphid (Koritsas and Garsed 1985) and lepidopteran (Jansson *et al.* 1991) infestations of crucifers with nitrogen fertilization have been established in previous studies, but are not consistently found (Jansson *et al.* 1991, McHugh and Foster 1995).

Weed species tend to grow faster and have shorter life-cycles compared with most annual crops and therefore have the capability to absorb nitrogen rapidly from the soil (Gwynne and Murray 1985). Nitrogen may be the most limiting macronutrient in the soil, and therefore the most important source of competition between weed and crop plants (Zimdahl 1980). Nitrogen-rich soil environments can show increased crop losses due to weed competition, compared with lower-fertility soil environments (Dyck *et. al.* 1995, Okumura *et. al.* 1986, Iwata *et. al.* 1980). Nitrophilic weed species such as lambsquarters (*Chenopodium album* L.) are particularly problematic in this context.

2.1.2 Plant Nitrogen

Nitrogen is taken up into the plant in the form of ammonium or nitrate ions. (Marschner 1995). Excess plant nitrogen can cause physiological problems related to nutrient balance with other constituents. For example, sulfur deficiencies can occur where nitrogen is in excess, and ammonium excess in particular can cause disruption in choroplast formation leading to yellowing of the leaves and necrosis (Nelson 1984, Marschner 1995).

Normally, nitrate from soil is absorbed into the root by active transport, translocated through the xylem and converted by nitrate reductase to NH_3. However, at high nitrate concentrations, nitrate reductase reserves can become depleted, and nitrate can accumulate in plant tissue (Nelson 1984, Marschner 1995). This accumulation commonly occurs in cruciferous vegetables (Lorenz 1978), and preferentially in stem and petiole tissue, followed by roots, leaves and lastly floral or reproductive parts (Nelson 1984, Mills and Jones 1979).

Links have been established between high nitrate consumption in humans and a condition called methemoglobinemia. This condition occurs when high levels of nitrates are reduced to nitrite in the human body (Corré and Breimer 1979), and interfere with the ability of hemoglobin to carry oxygen to tissues (Fan and Steinberg 1996). The toxic dose is dependent on body weight, making infants much more susceptible to this condition (Corré and Breimer 1979). A conservative estimate of a single toxic dose to humans is about 0.5 g of NO_3^--N (Lorenz 1978). German researchers have proposed a maximum acceptable nitrate concentration in fresh vegetables of 900 mg/kg for children under four months, and 1200 mg/kg for older children and adults (Corré and Breimer 1979).

From a crop quality perspective, sufficiency ranges (SR) have been proposed for most nutrient concentrations in the tissue of most common crops. Baldock and Schulte (1996) define the lower limit of the SR of a nutrient as the concentration at which 90 - 100% maximum yield is achieved, and the upper limit as the concentration where a yield decline is observed. Thus, soil nutrient levels that result in tissue concentrations above and below this range will have a detrimental effect on yield. Using specified sampling times and protocol, nutrient concentrations in plant tissue can be compared with these ranges as diagnostic measures of nutrient uptake to guide fertilizer application practices (Jones *et al.* 1971).

For corn, the SR is 2.8-3.5% total N on a dry weight basis for the ear leaf at the silking stage (Fageria *et al.* 1997). For beans, the SR is 3-6% total N on a dry weight basis for the uppermost fully developed trifoliate (Mills and Jones 1996). For broccoli, the SR is 3.2-5.5% total N on a dry weight basis for young, mature leaves sampled at floret emergence (Mills and Jones 1996).

Green beans (*Phaseolus vulgaris* L.), sweet corn (*Zea mays* L. *saccarata* Sturt.) and broccoli (*Brassica oleracea* L. var. *italica*) are good crops to use as bioassays to study nitrogen in the Delta agricultural system. These crops represent a range of nitrogen needs. Beans have rather low nitrogen requirements which are normally met through N-fixation (Fageria *et al.* 1997). Both corn (Fageria *et al.* 1997) and broccoli (Everaarts and Booij 2000) have high nitrogen needs, and broccoli is an effective nitrogen accumulator (Bowen *et al.* 1999).

2.1.3 Yields

Yield response to fertilizer input varies according to the crop nutrient requirements and residual soil nitrogen. In Iowa, the maximum yield of grain corn has been found at inputs of about 100 kg mineral N/ha (Cerrato and Blackmer 1990). However, in Tennessee it was shown that residual soil N levels can be high enough to prevent a yield response to nitrogen inputs in sweet corn (Straw *et al.* 1993). On Brunisols of Agassiz, B.C. broccoli marketable yields increased with mineral nitrogen applications up to 250 kg/ha (Agriculture Canada 1983). Maximum yields in broccoli are often observed where percent recovery of fertilizer N is low (Zebarth *et al.* 1995). This reveals the possible tension between maximizing yield and preventing nitrogen losses to leaching. Most research on nutrient inputs for beans focuses on nutrients other than nitrogen, since N-fixation can meet the nitrogen needs of this crop.

Crop vegetative growth tends to increase with nitrogen supply, sometimes at the expense of growth and maturation of reproductive plant parts (Mills and Jones 1979, Marschner 1995). In corn and grains, the elongation of stem tissue can lead to lodging which can become the most important yield-limiting factor in extreme cases (Marschner 1995). In broccoli, Kowalenko and Hall (1987) found that mineral nitrogen applications from 0 - 250 kg/ha did not increase vegetative growth.

2.2 Nitrate Leaching in the Fraser Valley

Experiments using ^{15}N tracers in Agassiz, B.C. (Figure 1.1) show that there is very little leaching of nitrate during the growing season, but virtually complete nitrate leaching over the winter because of the mild temperatures and high rainfall (Kowalenko 2000).

Although leaching studies have not been done specifically in Delta, Bomke *et al.* (1994) reviewed work in The Netherlands and in Scotland, with similarly humid climates to British Columbia, which showed that >300 mm of cumulative precipitation in winter caused leaching of 100% and 80% total soil nitrate respectively. Because November to April rainfall averages approximately 690 mm in Delta[3], complete nitrate leaching is likely to occur over the winter there as well. Although unusually low rainfall in specific years may not result in 100% nitrate loss, soil nitrate levels before the high rainfall period represent the maximum potential for nitrate leaching.

Planting cover crops in late summer can be an effective way to sequester excess nitrogen over the winter in agricultural systems of this region and prevent nitrate leaching (Nafuma 1998).

[3] Environment Canada Canadian Climate Normals
http://www.msc-smc.ec.gc.ca/climate.climate_normals/index_e.html

2.3 Predicting Appropriate Manure Application Rates

2.3.1 Available Soil N

One of the greatest challenges for farmers converting to organic practices is providing sufficient mineral N from organic sources. The transitional period can be a time of decreased yields, since nitrogen from organic fertilizers is not always mineralized by the time of rapid crop uptake. This deficit is particularly acute for crops with a high nitrogen demand, such as corn (Pang and Letey 2000). However, repeated applications of organic fertilizers builds up a store of available N in soil (Carpenter-Boggs *et al.* 2000). After 3-5 years, this pool is a significant contributor to the crop N uptake, and buffers the lag between crop uptake and mineralization of organic fertilizer nutrients (Pang and Letey 2000). Often, yields increase to previous levels once this has been achieved.

Cover cropping practices (Vyn *et al.* 1999) and including legumes in a rotation (Carpenter-Boggs *et al.* 2000) can also contribute to available soil N. Such practices can reduce the need for nitrogen inputs (Pang and Letey 2000, Vyn *et al.* 1999, Pratt *et al.* 1973) by increasing available soil N. For organic farmers in Delta, this represents an important source of nitrogen for crops, and must be considered in order to predict efficent rates of fertilizer input.

2.3.2 Crop N-uptake

Plotting total crop N-uptake against the rate of nitrogen applied often results in a curvilinear relationship showing a clear maximum uptake and decreased uptake-efficiency after a certain rate (Fageria *et al.* 1997, Zebarth *et al.* 1995). These relationships can reveal the nitrogen application rates that will result in optimal uptake and minimal leaching losses, and can therefore be an important tool for prediction in Delta.

2.3.3 Potentially Mineralizable Nitrogen

Laboratory incubation experiments are generally accepted as an accurate but time-consuming way to determine the potentially mineralizable nitrogen (PMN) of manures (Serna and Pomares 1990). However, rapid chemical methods of predicting the results of incubation experiments are desireable. The nitrogen mineralization rate of poultry manure is of critical importance when predicting application rates which will provide sufficient nitrogen to crops and minimize nitrate leaching (Gordillo and Cabrera 1997a, Bitzer and Sims 1988).

Attempts to characterize the dynamics of manure nitrogen mineralization over time in soil have resulted in a commonly used model for prediction, explained by Talpaz *et al.* (1981):

$$N_t = PMN[1\text{-}\exp(\text{-}kt)] \qquad [1]$$

where N_t = mineral nitrogen at time, t

k = rate constant

PMN= potentially mineralizable N at t=0

Using this model, Qafoku et. al. (2001) determined PMN for 99 manure samples using 10 measurements of N_t. Regressing these PMN values from incubation results against water-soluble organic nitrogen values and PMN predicted by near-infrared spectroscopy predicted 87% and 81% of the variation in PMN respectively.

Some authors now use a modification of this nonlinear model, based on the premise that there are two main "pools" of mineralizable nitrogen in poultry manure. Hadas *et al.* (1983) suggests that the two pools represent entirely different substrates. The first substrate to mineralize, usually within the first week, is the "fast pool". The second is the "slow pool" which mineralizes at a much slower rate after the first week. This theory is based on the well-replicated mineralization pattern of poultry manure that shows rapid mineralization followed by a sudden levelling-off (Gordillo and Cabrera 1997a, Bitzer and Sims 1988, Gale and Gilmour 1986, Hadas et. al 1983, Castellanos and Pratt 1981). The modified model is as follows:

$$N_t = PMN_f[1\text{-}\exp(\text{-}k_f t)] + PMN_s[1\text{-}\exp(\text{-}k_s t)] \qquad [2]$$

where all variables are as in Equation [1], and subscripts *f* and *s* refer to the variables for fast and slow pools, respectively.

Using this model, and the same calculation and statistical procedure as Qafoku *et al.* (2001), Gordillo and Cabrera (1997a) were able to predict potentially mineralizable nitrogen (PMN_f + PMN_s) with uric acid nitrogen ($r^2 = 0.92$), total nitrogen determined by dry combustion

($r^2 = 0.83$), total nitrogen and uric acid nitrogen ($R^2 = 0.91$) and uric acid nitrogen and C:N ($R^2 = 0.95$).

Simpler approaches that do not use the nonlinear model have also yielded predictive tools. In a simple linear regression, Serna and Pomares (1990) found that N extracted by the autoclave method ($r^2 = 0.912$) , by permanganate ($r^2 = 0.884$) and by pepsin ($r^2 = 0.871$) were all good predictors of the N mineralized in a 6-week incubation. Castellanos and Pratt (1981) also found N released by pepsin ($r^2 = 0.81$) to be a good predictor of nitrogen released in a 10-month barley and sudangrass cropping experiment carried out in a greenhouse. At 10 weeks, mineral N released in an incubation experiment could predict 81% of the variation in the mineral N in the 10-month cropping experiment.

The potential usefulness of any of the variables discussed above for informing application rates in Delta is limited by the access farmers have to these tests. Any prediction tools developed should be accessible and understandable to farmers. Water soluble organic nitrogen, near-infrared spectroscopy, and permanganate, pepsin, and autoclave N-extractions are not part of the routine workings of the commonly used soil and fertilizer analysis laboratories in the area. While some of these techniques may be feasible in a university setting, farmers cannot rely on this as a regular source of information. Furthermore, variability in field conditions and error in application rates will dictate the degree of precision that is useful to farmers in Delta.

For the purposes of continuing to look for good chemical predictors of mineralized nitrogen, it does not seem worthwhile to use the approach of Gordillo and Cabrera (1997a) and Qafoku *et al.* (2001). This method determines PMN for manure samples through a time-series of incubation extractions. The more straightforward attempt of Serna and Pomares (1990) to find variables that will predict N_t at an arbitrary t value seems equally as effective. The variables used should be limited to those that are included in routine manure testing and familiar to farmers: total nitrogen, C:N, and initial mineral nitrogen content of the manure source.

A further limitation on the usefulness of these results is on how well they approximate mineral nitrogen levels in the field. Incubation experiments provide a measurement of potentially mineralizable nitrogen under ideal or near-ideal conditions for mineralization, which occur at about 25°C and 60% of soil pore space filled with water (Brady and Weil 1999).

However, temperature differences between the field and lab may not be an important source of variability between mineral N measured in laboratory and field experiments. In their review of decomposition data Walse *et al.* (1998) report that the effect of temperature on decomposition (mineralization) rate is less important for nutrient-rich materials, which would include poultry manure. In an incubation study of poultry manure on sandy soil, Hadas *et al.* (1983) found that there was no difference in amount of mineral nitrogen in pots incubated at 14, 25 and 35°C after one week. In a study conducted in 1994 and 1995 in spring barley and winter wheat plots in Delta, Krzic (1997) reported minimum soil temperatures of around 14°C by May 15, at a depth of 20 cm.

Water deficit is more likely to cause variation between lab and field results, given the distribution of precipitation in this region, which is biased toward winter months. Kowalenko (2000) does not identify leaching or denitrification due to water excess as significant sources of nitrogen loss during the growing season from agricultural systems in south coastal B.C.

2.4 Summary

The above discussion illustrates that the abundance of poultry manure available to Delta farmers must be used prudently to ensure that crop quality and environmental safety is ensured. Excessive manure nitrogen may affect parameters that negatively impact crop yields and food safety. Furthermore, the Fraser Valley is vulnerable to nitrate pollution because of its humid climate, and this must continually guide agricultural practices. Laboratory and field methods can be employed to predict application rates of organic fertilizers that optimize crop quality and environmental concerns.

3. Materials and Methods

3.1 Study Sites

Experimental plots were established in early May 2001 on commercial certified organic corn *(Zea mays* L. *saccarata* Sturt.; variety "Sweet Tooth"), green bean (*Phaseolus vulgaris* L.; variety "Celtic") and broccoli (*Brassica oleracea* L. var. *italica*; variety "Green Belt") fields in Delta, B.C. The corn and bean sites were located on a field extending west from Arthur Drive, approximately 2 km north of the Deltaport Way turnoff, opposite the Sacred Heart Parish. The broccoli site was located on a field on the west side of 40th street at the 3700 block, halfway between the C.A. Waddell Canal and the dead end.

The soils at both sites were categorized as a complex of the Delta and Blundell series. These two soils were mapped as Orthic Humic (Delta) and Rego Humic (Blundell) Gleysols, both developed from fluvial parent material (Luttmerding, 1981). The main difference between these two series is that the Blundell soil formed in hollows and accumulated a 22 cm-thick layer of organic material above the mineral soil surface. However, practices such as laser-leveling, drainage and tillage have largely eliminated this layer. Therefore, these two series are more similar today than they were at the time of mapping. Texture is silt loam (Delta) to silty clay loam (Blundell) in the plow layer, with poor (Delta) to very poor (Blundell) natural drainage (Luttmerding, 1981).

The field containing the corn and bean experiments has been farmed by Brent Harris of Fraserland Organics since 1996, and since that time has been divided into three sub-fields of equal size and managed with a sweet corn-potato-green bean rotation. In the sub-field where the experimental bean plot was situated, broccoli had been grown in 1998. Manure is applied at a rate of approximately 25 m^3/ha (10 t/ha) on each crop each spring. Directly after manure spreading, the fields are disked to a depth of 12 cm, then subsoiled to a depth of 20 cm a couple of days later. Every bean crop is followed by a cover crop, usually planted in late August.

In 2001, corn was direct-seeded at a density of 45 000 per hectare on May 21 and beans were direct-seeded at a density of 180 000 per hectare on May 29. After harvesting the beans and before planting the cover crop, the field was treated with $CaCO_3$ at 6.2 t/ha and bone meal at 1120 kg/ha. It was then disked to a depth of approximately 5 cm and seeded with a barley cover crop (*Hordeum vulgare*, var. Dolly), at a rate of 170 kg seed/ha.

The broccoli field has been farmed by Danny Chong of Bo Chong Enterprises since 1999. It was in grassland set-aside in 1999, and potatoes were grown in 2000. The grassland set-aside was not manured, and potatoes were manured at a rate of 25 m^3/ha.

In 2001, to control clubroot infection in broccoli, seed was started in a seedbed off the experimental site in two seedings, on June 20 and June 30. The seedbed was manured at a rate of approximately 36 m^3/ha. Seedlings were covered with a remay cover, watered with a compost tea, and harvested by hand. The experimental site was rotovated four times between the date of manure spreading and crop planting, to a depth of 20 cm. The older seedlings were planted into blocks 3, 4 and one adjacent plot of block 2 on July 28. The younger seedlings were planted on July 29 into block 1 and the remaining four plots of block 2. Planting density was approximately 74 000 plants per hectare, with 90 cm between rows and 15 cm between plants within a row. Broccoli plants were irrigated the day after planting in the experimental site. For pest control, soap was sprayed during the last week of August and *Bacillus thuringiensis* and soap were sprayed in the first week of September.

3.1.1 Fertilizer Treatments

Experiments were set up in a randomized complete block design with four blocks and five organic fertilizer treatments. The layout for the corn and bean experiments is shown in Figure 3.1, with planting direction perpendicular to the length of the blocks and about 12 rows per plot for corn and 20 rows per plot for beans. The layout for the broccoli experiment is shown in Figure 3.2. The length of the plots was parallel to the direction of planting, with about 4-5 rows of broccoli per plot width. The experimental design was changed for the broccoli experiment after noting that the design for the corn and bean experiments was not well-suited to the spreader width and turning radius. Thus, the spreader drove over the plots several times to apply each treatment causing soil compaction and difficulties in accurately measuring the field application rate. The plot size and shape in the broccoli experiment allow the spreader to completely apply the treatment with just one pass over the plot being treated.

The following treatments were applied to corn and bean plots on May 3, 2001, as depicted in Figure 3.1., and to the broccoli plots on May 29, 2001, as depicted in Figure 3.2.:

1) poultry manure, one pass of the spreader

2) poultry manure, two passes of the spreader (double application)

3) composted yard trimmings, one pass of the spreader

4) a combination of the two materials, one pass of the spreader of each (for corn and beans); and one pass of a pre-made 1:1 volume mix for broccoli

5) control, no amendments added.

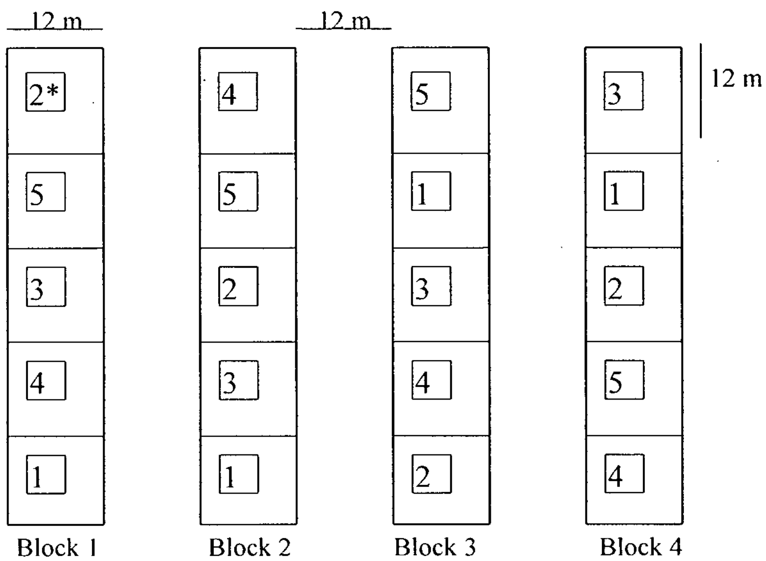

Figure 3.1. Experimental layout on sweet corn and bean fields.
*numbers represent treatments described in Section 3.1.1.

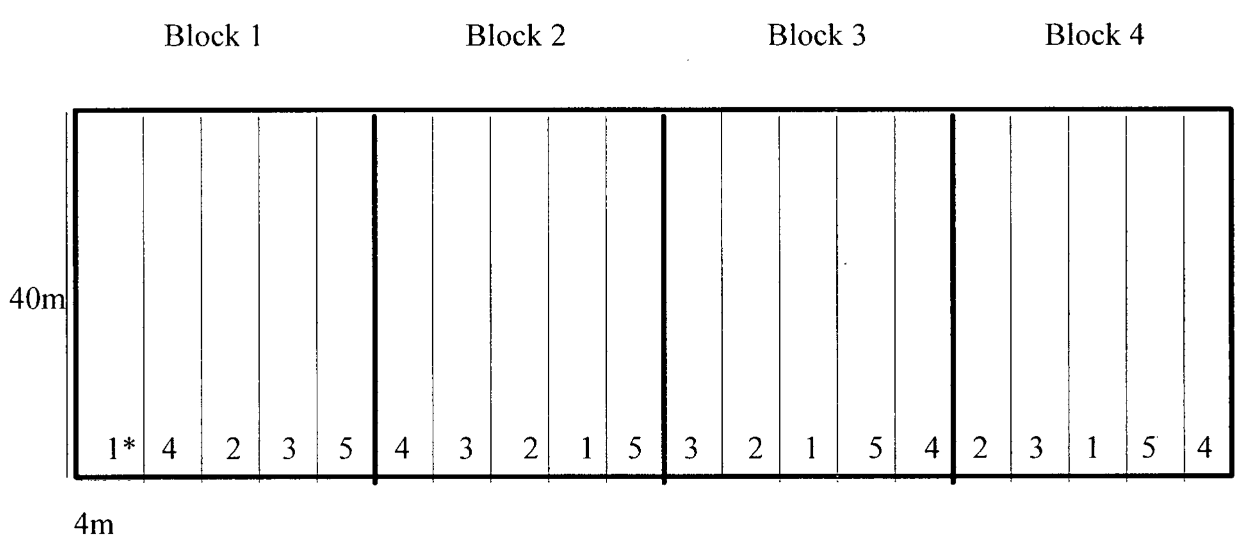

Figure 3.2. Experimental layout on broccoli field.
*numbers represent treatments described in Section 3.1.1..

Rates of application were measured by having the manure spreader drive over a tarp of known area, measuring the mass and volume of the fertilizer on the tarp and converting this to a measurements for all treatments are presented in Table 3.1, using gravimetric water content measurements for conversions to dry rate. Considerable variation in application rate occured as a result of variation in fertilizer water content. In the broccoli field, two sources of poultry manure were available, but neither was sufficient to use for all the treatments. The source used for the manure treatments on blocks 3 and 4 was one year older than the other source and retained much more moisture. It was therefore delivered at heavier rates from the spreader. However, the nitrogen content of this source was lower (3.26%) than the drier source (4.76%). The nitrogen delivery from the two sources of poultry manure was not significantly different (Table A.1).

Table 3.1. Application rates of fertilizer treatments on three field experiments.

Experiment	Treatment	Fresh Rate (t/ha)	Dry Rate (t/ha)	kg N/ha
Corn, Beans	manure x 1	13.9	9.6	403
	manure x 2	27.8	19.2	806
	compost	5.8	3.4	54
	mix	19.7	13.0	157*
Broccoli	manure x 1 (blocks 1, 2)	8.0	5.8	278
	manure x 1 (blocks 3, 4)	19.0	10.0	326
	manure x 2 (blocks 1, 2)	16.0	11.6	556
	manure x 2 (blocks 3, 4)	38.0	20.0	652
	compost	9.0	4.5	63
	mix	8.0	4.5	130

*estimated from N delivery by compost and manure x 1 treatments

Two composite samples of fertilizer materials were taken, the first by combining one trowel-sized scoop from each of the tarp trials, the second by combining samples from several locations on the spreader. The mix was not sampled in the corn and bean experiments because it was not pre-made, but applied as successive applications of the manure and compost. Total nitrogen was determined on a semi-micro Kjeldahl digest (Bremner and Mulvaney 1982). Total carbon was analyzed using a LECO Carbon Analyzer for a dry combustion method (Nelson and Sommers 1982), and available NH_4^+ and NO_3^- were found using a potassium sulfate extract, determined colourimetrically on a Technicon Autoanalyzer for NH_4^+-N and a Turner Spectrophotometer for NO_3^--N. This method is based on the one outlined by McKeague (1978), and modified to use K_2SO_4 rather than KCl due to the interference of Cl^- ions with the colour complex that forms for nitrate measurement.

Table 3.2. Chemical analyses of experimental fertilizers.

Experiment	Material	Total N*	C:N	NH_4^{+*}	NO_3^{-*}
Corn, Beans	Manure	42	10.9	3.0	0.3
	Compost	16	17.1	1.7	0.8
Broccoli	Dry Manure (blocks 1,2)	48	7.7	2.4	n/a
	Wet Manure (blocks 3,4)	33	10.6	10.5	n/a
	Mix	29	10.8	1.3	1.5
	Compost	14	21.4	4.7	0.5

* g/kg dry material

3.2 Experimental Conditions

To determine the soil fertility status of the experimental area, 15 soil samples were taken with a 2.5 cm diameter Oakfield probe from a depth of 0-20 cm in a uniform pattern from each block on each experimental site. These samples were air-dried and ground using a soil hammer mill with a 2 mm sieve. Soil pH was determined using a Radiometer pH meter on a 1:1 soil to distilled water slurry (McLean 1982), and electrical conductivity was measured from the same slurry (U.S. Salinity Lab Staff, 1954). Organic matter was calculated by analyzing total organic carbon using a LECO Carbon Analyzer for a dry combustion method (Nelson and Sommers 1982) and multiplying by 1.724 (a conversion factor based on the assumption of 58% C in organic matter). Total nitrogen was determined colorimetrically on a semi-micro Kjeldahl digest using a Technicon Auto-Analyzer (Bremner and Mulvaney 1982). Available phosphorus was determined colourimetrically using the ascorbic acid method on a 1:10 soil:Bray P_1 extract (McKeague 1978). Available calcium and magnesium were determined by Perkin-Elmer Atomic Absorption Spectrophotometer on a 1:5 soil:ammonium acetate extract (Thomas 1982). Mineral nitrogen content was analyzed according to McKeague (1978), modified to use a 1M KCl extracting solution for a 1:10 soil:KCl extract. Extracts were analyzed for NH_4^+-N and NO_3^--N using a Lachat QuikChem FIA+, 8000 series. Gravimetric water content for each sample was determined at the time of extraction and used to calculate soil mineral nitrogen on an oven-dry (105°C) weight basis.

Because the there was little variability among the four blocks at each experimental site, mean values for the four blocks were calculated for reporting (Table 3.3).

In all experimental sites before treatment application, available phosphorus and potassium were both well over the "very high" standards according to Neufeld (1980), set at 70+ ppm for P and 175+ for K. No additional Mg input is required, according to Neufeld (1980). In general, the soils are nutrient-rich.

Also of note are the differences between the corn and bean fields and the broccoli field. Organic matter, pH, electrical conductivity, mineral and total N and available calcium and magnesium were all slightly lower in the broccoli field compared to the corn and bean fields, which were more similar to each other. This is likely a result of the differing management histories of the sites.

Table 3.3. Soil chemical properties on three field sites before treatment application.

Field	pH (in H_20)	E.C. (dS/m)	O.M. (%)	Mineral N (mg/kg*)	Total N (g/kg*)	-Available Nutrients (ppm)-			
						P	K	Ca	Mg
Corn	5.15	0.46	8.5	11	3.6	174	278	1700	284
Beans	5.23	0.49	9.3	10	3.7	182	304	1913	281
Broccoli	4.83	0.35	6.2	6.2	2.3	250	295	1325	146

*on a soil dry weight basis

Mean maximum and minimum temperatures and precipitation over the experimental period were compared with climate averages (Figures 3.3, 3.4 and 3.5). Data was obtained from Environment Canada's Delta Tsawwassen Beach climate station. Temperatures during the study period closely approximated averages for that station. The only exceptions were the warmer January and cooler February in 2001 relative to long-term averages. Precipitation was erratic over the study period, with November 2000 - May 2001 being drier than average, and June - August and October 2001 showing higher precipitation than average. The total precipitation from November 2000 to April 2001 was 403 mm. Although this was 287 mm less than average (Fig. 3.5), it was likely sufficient to cause complete nitrate leaching of soil residual nitrogen from the 2000 growing season (Bomke *et al.* 1994).

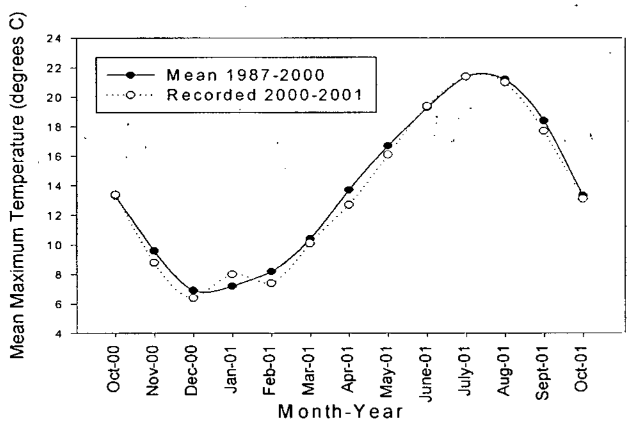

Figure 3.3. Maximum monthly air temperatures for Delta Tsawwassen Beach climate station.

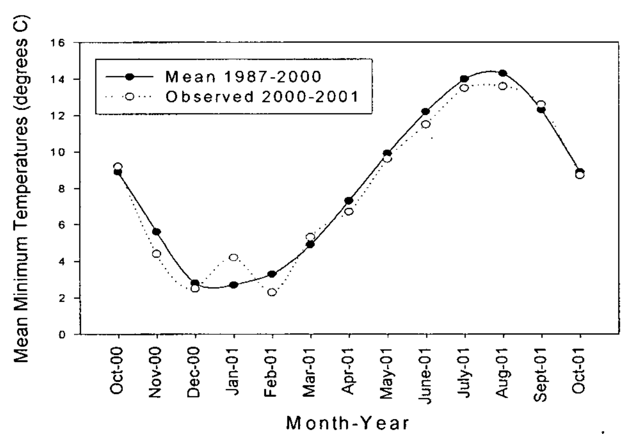

Figure 3.4. Minimum monthly air temperatures for Delta Tsawwassen Beach climate station.

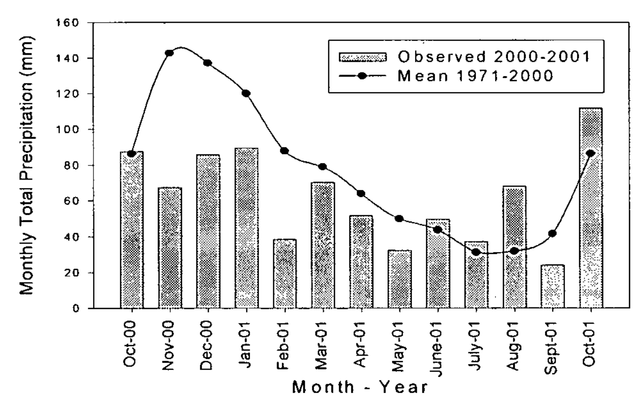

Figure 3.5. Total monthly precipitation for Delta Tsawwassen Beach climate station.

3.3 Assessment of Crop Quality

Crop quality was defined by a complex of agronomic indicators: disease incidence and severity, weed frequency and abundant cover, insect predation of crops, diagnostic levels of tissue nitrogen, and vegetative biomass and marketable yields at harvest. These indicators were chosen as they represent primary agronomic concerns of the Delta farmers. Crop diseases and pests which were identified as problematic by local farmers, or by the staff of E.S. Cropconsult, a pest management company working in Delta, were assessed. Clubroot (*Plasmodiophora brassicae*) in broccoli, and grey mold (*Botrytis cinerea*) and rhizoctonia root-root (*Rhizoctonia solani*) in beans were scored. No disease was identified as a significant threat to corn in this region, hence no assessment was done. Only broccoli was threatened by insect pests.

3.3.1 Broccoli - Clubroot Assessment

In mid-October 2001, 10 broccoli plants were selected randomly between 5 m and 35 m in each plot for clubroot (*Plasmodiophora brassicae*) grading. The plants were removed from the soil using a shovel and the soil was removed from the roots. The percentage of the total volume of the root system (roots and space between roots) which was affected by clubroot galls was evaluated according to the following scheme:

0 = no clubroot present
1 = 1-5% of rooting volume affected
2 = 6-25% of rooting volume affected
3 = 26-50% of rooting volume affected
4 = 51-100% of rooting volume affected.

This grading scheme is a modification of that used by Dixon and Robinson (1986) and Dixon *et al.* (1987). A numerical range was assigned to each grade in our scheme, where Dixon's scheme contained two grades that were described solely qualitatively. Also, grades 2 and 3 in this scheme are a single grade in Dixon's scheme.

3.3.2 Beans - Grey Mold and Rhizoctonia Root-Rot Assessment

Grey mold (*Botrytis cinerea*) assessment was done at the time of harvest, in mid-August. For all the plants collected in the experimental harvest, the presence or absence of grey mold was indicated by a 1 or a 0 for all leaves and stems. The grades were then totalled separately for leaves and stems for each plot.

Assessment of rhizoctonia root rot (*Rhizoctonia solani*) infection in the bean plots was done in late July 2001, and again at harvest, in mid-August 2001. In July, twelve random plants were graded along a transect in a representative row as close to mid-plot as possible. At this time nodulation on bean roots was also assessed, by counting the nodules on each plant graded.

At harvest, a subsample of five random plants from the harvested area was analyzed. Root cover by rhizoctonia was measured by estimating the total surface area of the main root that showed evidence of rhizoctonia infection. This was done for each plant according to the following scheme:

0 = no infection,

1 = <1% total root surface affected

2 = 1-5% total root surface affected

3 = 6-20% total root surface affected

4 = 21-50% total root surface affected

5 = 51-100% total root surface affected.

This grading scheme is a modification of that of Ahmed *et al.* (1994), which employed equally spaced ranges for the latter five grades.

3.3.3 Weed Surveys

Weed surveys were carried out on bean plots in mid-August 2001 and corn plots in late August 2001. Broccoli plots could not be surveyed because the farmer cultivated regularly. In both corn and bean plots, a representative row close to mid-plot was selected and a 10 m rope with marks at each metre was placed on the ground. The weed species present were identified and given a frequency rating from 1-10, according to the number of 1 m segments in which they appeared. Each weed species named was then given a Braun-Blanquet cover-abundance rating (Table 3.4).

Table 3.4. Braun-Blaunquet cover-abundance scale.
(from Principe 2001)

Symbol	Class	% Cover	Abundance Class
r	-	less than 1	solitary
+	very rare	less than 1	few
1	rare	1-5	numerous or scattered
2	occasional	6-25	any number
3	frequent	26-50	any number
4	common	51-75	any number
5	abundant	76-100	any number

This scale is criticized for its subjectivity, but widely used mainly because practical objective methods have not been developed (Principe 2001). In this study, the cover-abundance classes identified by surveyors were not compared with objective measurements of cover. However, the weed surveys were always carried out by the same surveyors which helps keep measurements comparable among treatments. Furthermore, the data was complemented by the objective frequency rating. Therefore, differences in weed presence patterns between treatments will likely be visible, if not comparable to objective measurements.

3.3.4 Insects

On August 20, 2001, broccoli plots were sampled for insect pests, according to the methods used by E.S. Cropconsult. Three plants from a middle row of each plot were taken; at approximately 5, 20 and 35 m from the end of the plot (Figure 3.2). On each plant, counts were made of the following pest species: green peach aphid (*Myzus persicae* Sulzer), cabbage aphids (*Brevicoryne brassicae* L.), the larvae of diamondback moths (*Plutella xylostella* L.), cabbage loopers (*Trichoplusia ni* Hubner) and imported cabbage moths (*Pieris rapae* L.).

Beneficial species observed were lacewings, the aphid-parasitizing fungus *Pandora neoaphidus* and the parasitic wasp *Aphidus sp.* The presence of the former was scored by counting the rust-coloured aphids, and the latter was scored by counting the bloated aphids.

3.3.5 **Diagnostic Plant Tissue Sampling**

Corn tissue samples were taken in mid-August, 79 days after planting, corresponding to the R1 stage - silking (Ritchie and Hanway 1984) which is appropriate for diagnostic measurements (Dow 1980, Fageria *et al.* 1997). Two adjacent rows, representative of the whole plot in size and colour were selected, as close to mid-plot as possible. The leaf opposite the ear node was sampled according to Dow (1980) from 10 random plants in these two rows.

Bean tissue samples were taken in late July, 59 days after planting, corresponding to the R1 stage - one flower open at any node (Lebaron 1974). A single representative row was selected in each plot, well away from the rows to be harvested. The uppermost fully developed trifoliate was selected according to the method of Jones *et al.* (1990), from 12 random plants along this row.

Broccoli tissue samples were taken in mid-September, 74 (second planting) or 84 (first planting) days after seeding in the seedbed, corresponding to the first bud emergence. One young, mature leaf was sampled from twenty random plants according to the method outlined by Lorenz and Maynard (1980).

All plant material was dried completely at 50°C in cotton bags, ground using a Thomas-Wiley Laboratory Mill (Model 4 by Arthur H. Thomas Company), and analyzed for total nitrogen according to Parkinson and Allen (1975).

As a further diagnostic sample, broccoli heads collected at harvest were also analyzed for nitrate-N according to Bremner (1965) as a measure of potential toxicity to humans. This method measures the total nitrogen by the macro Kjeldahl method, both including and excluding nitrate. The former was subtracted from the latter to obtain nitrate concentrations.

3.3.6 Yields and Crop N Uptake

Corn, bean and broccoli plots were harvested on September 12, August 12, and September 28, 2001, respectively. In each plot, two metres of a row representative of the entire plot in colour and height, as close to the middle of the plot as possible, were stripped of all above-ground crop material. Vegetative and reproductive parts were separated, placed in cotton bags, and total marketable crop and vegetative biomass were weighed. Corn stalks, tillers and cobs were counted in the harvested area.

Due to a high volume of harvested material which is difficult to transport and process, a random subsample of three corn cobs and stalks were kept, and a random subsample of vegetative parts of three broccoli plants were kept. All harvested broccoli florets were kept. For all three crops, vegetative and reproductive material were dried completely in separate cotton bags at 50°C. Biomass on a dry weight basis and plant moisture content were calculated. Dried plant material was ground using a Thomas-Wiley Laboratory Mill (Model 4 by Arthur H. Thomas Company), and analyzed for total nitrogen according to Parkinson and Allen (1975).

The total crop N uptake at harvest was calculated by multiplying the percent total nitrogen in vegetative tissue by the total dry biomass of vegetative parts and summing this with the same calculation for reproductive parts.

3.4 Assessment of the Potential for Nitrate Leaching

On November 3, 2001, soil samples were taken in each plot of all three fields to measure the residual nitrogen in the soil after crop harvest. Using a 2.5 cm diameter Oakfield probe, eight soil samples were taken per plot to a depth of 30 cm. The soil samples were analyzed for mineral nitrogen according to the KCl extraction procedure in section 3.2. Ammonium was not included in the statistical analyses, as it was not significantly different from zero (Table A.2) and was negative in many cases, when control levels were subtracted.

On November 3, 2001, the barley cover crop on the bean field was sampled by harvesting all aboveground biomass rooted within a 0.5 x 0.5m quadrat, placed randomly within the plot. This material was dried completely in cotton bags at 50°C, ground and analyzed for total nitrogen according to Parkinson and Allen (1975).

3.5 Predicting Appropriate Manure Application Rates

3.5.1 **Potentially Mineralizable Nitrogen from Two Poultry Manure Rates**

In early May, twenty manure piles from Delta were sampled. Manure piles consist of about 30-35 m^3 of manure, piled and stored for spreading. These samples were analyzed for total C, total N, NH_4^+ and NO_3^- according to the methods outlined in section 3.1.1. Mean, standard deviation and coefficient of variation (C.V.) for all variables were calculated. The samples were analyzed for gravimetric moisture content and bulk density.

Forty-eight 500 mL-capacity plastic pots with six ventilation holes in the rim were filled with 400 grams of fresh soil from a cultivated field in Delta, adjacent to the experimental site with corn and bean trials. Before being placed in the pots, the top layer of soil (about 2 cm), containing ungerminated grass seed, was scraped away and the soil was sieved through an 8 mm sieve before being placed in the pots. Twelve samples of the same soil were placed in moisture cans, and oven-dried at 105°C to obtain gravimetric water content, which enabled calculation of the mass of dry soil per pot.

The manure samples were applied to twenty pots of soil at a simulated rate of 3.7 dry tonnes/ha (approximately 5 t/ha fresh), where a 20 cm furrow slice and a soil bulk density of 1.0 t/m^3 were assumed. A further twenty pots of soil were treated with the same manure samples at a simulated rate of 7.5 dry tonnes/ha (approximately 10 t/ha fresh), which represents a common rate used in Delta. Four pots were prepared with a known nitrogen content by simulating a 100 kg N/ha application using a solution of dissolved 34-0-0 fertilizer. Four were left untreated as controls. The pots were placed in random order in two cardboard boxes and incubated at approximately 20°C. Soil was maintained at about 26 - 30% moisture content by watering as needed, where field capacity is 33% (Figure C.1).

At 31 days and 74 days of incubation, about 13 grams of soil from the centre of each pot was extracted and analyzed for mineral nitrogen using the KCl extraction procedure described in section 3.2. The fertilizer nitrate-N in the extracts was converted to mg of NO_3^--N/kg soil and then to kg NO_3^--N/ha using an assumed soil bulk density of 1.2 t/m^3. (see Appendix B for a sample calculation). This is a better approximation of the mean soil bulk density in Delta later in the growing season (Weinberg 1987) than the assumed bulk density of 1.0 t/m^3 used for simulating application rates.

The amount of total fertilizer N present as NO_3^--N was calculated at each sampling time. The mean nitrate levels of control pots was subtracted from the fertilized pots. The difference was divided by the total N applied per pot and multiplied by 100. This does not give an estimate of net mineralization, since initial mineral N of the fertilizer was not subtracted.

3.5.2 Potentially Mineralizable Nitrogen from Mixtures of Composted Yard Trimmings and Poultry Manure

Thirty-six 500 mL plastic pots with six ventilation holes in the rim were filled with 400 grams of fresh soil from the same location as the previous experiment. The soil was collected, processed and analyzed for moisture content and mineral nitrogen as described above.

The manure used in this experiment was taken from the source applied to blocks 1 and 2 on the broccoli field trial. The compost used was taken from the compost source used in the same trial. Manure and compost were analyzed for gravimetric moisture content and bulk density using moisture cans, and for total C, total N and mineral N as described in section 3.1.1.

Manure and compost were added to the soil pots in the following manure:compost volume ratios: 100:0, 75:25, 67:33, 50:50, 33:67, 25:75, 0:100. Four pots of each ratio were prepared, for a total of 28. Total fertilizer material was applied per pot at a simulated rate of 25 m^3/ha (approximately 10 t/ha), based on an assumed 20 cm furrow slice and a soil bulk density of 1.0 t/m^3. Four pots were prepared with a known nitrogen content by simulating a 110 kg N/ha application using a solution of dissolved 34-0-0 fertilizer. Four were left untreated as controls. The pots were placed in random order in two cardboard boxes and incubated for 61 days at approximately 20°C, with sampling at 30 and 61 days. Controlling of soil water content, sampling, mineral N analysis and calculations were done as described for the previous experiment.

3.5.3 Nitrogen Mineralization in Field Experiments

An estimate of total fertilizer N present as mineral N was obtained after the period of rapid mineralization and crop uptake. Soil samples were taken on August 16 for corn, July 26 for beans and September 12 for broccoli. Ten cores per plot were taken from a depth of 0-15 cm in a uniform pattern from each plot. These were stored in a cooler in the field and overnight in a 4°C refrigerator and analyzed for mineral nitrogen according to section 3.2.

Total mineral N for the treatments was calculated by converting total crop N, calculated at harvest, and soil mineral N from the above samplings to kg/ha and summing them. There was a difference of approximately two weeks between the soil sampling dates and the crop harvest for each experiment. The total mineral N could be underestimated if nitrogen was lost during these two weeks, but this is unlikely. The broccoli measurements were taken in September, which was a dry month (Fig 3.5). The bean and corn measurements were taken in August, when total rainfall was 68.1 mm, compared with a long-term mean of 32.0 mm. However, only a portion of this would have fallen during the relevant two-week period, and it does not approach levels sufficient to cause high nitrate leaching (Bomke *et al.* 1994). Overestimation could occur if plant uptake was high during the two-week period. However, during this time there was likely very little plant N uptake, as the stage of rapid growth for each of the crops had passed. Therefore, the risk of overestimation is small.

The total mineral nitrogen in the treatment, minus the mean of control plots, was divided by total fertilizer nitrogen applied, and multiplied by 100. This provides an estimate of percent fertilizer N mineralized over the growing season, but like the calculations for laboratory experiments, does not show net N mineralization, since it does not subtract initial mineral nitrogen in the fertilizer source.

For the control plots, this calculation provides as estimate of the available soil nitrogen without fertilizer inputs.

3.6 Statistical Analyses

Data obtained in field experiments were analyzed in a one-way analysis of variance, using the ANOVA procedure (SAS Institute, 1990). Data sets of subjectively assessed grades were converted to the mid-point of the range that they represented, to correct for unequal grade ranges (Table B.1). These converted grades were then analyzed using the above procedure. Where treatments differed significantly, Duncan's multiple range test was used to assess the differences among treatments.

For the incubation experiment with two manure rates, the mean and coefficient of variation (C.V.) were calculated for the twenty samples at both application rates and both sampling times. Simple linear regression analyses tested the strength of the relationship of manure nitrate with C:N, total N, and initial NH_4^+ of the manure samples for each application rate at each sampling time.

For the incubation experiment using mixtures of composted yard trimmings and manure, linear regression analyses provided the equations of the lines of the relationships between mineral nitrogen and the proportion of compost in the fertilizer mix for the 30 and 61 day samplings.

4. Results and Discussion

4.1 Crop Quality

4.1.1 Broccoli - Clubroot Assessment

Clubroot (*Plasmodiophora brassicae*) showed reduced severity in plots with higher nitrogen supply capabilities (Figure 4.1, Table A.3). This response is congruent with the results of other authors (Lazarovits and Conn 1997, Dixon *et al.* 1987). High mineral nitrogen levels (Lazarovits 2001, Dixon *et al.* 1987) as well as increased microbial diversity (Gorodecki and Hadar 1990, Lazarovits 2001) have been shown to cause a reduction in soil-borne fungal diseases such as clubroot. In this study, no tests were done to determine which of these factors caused the reduction in clubroot severity.

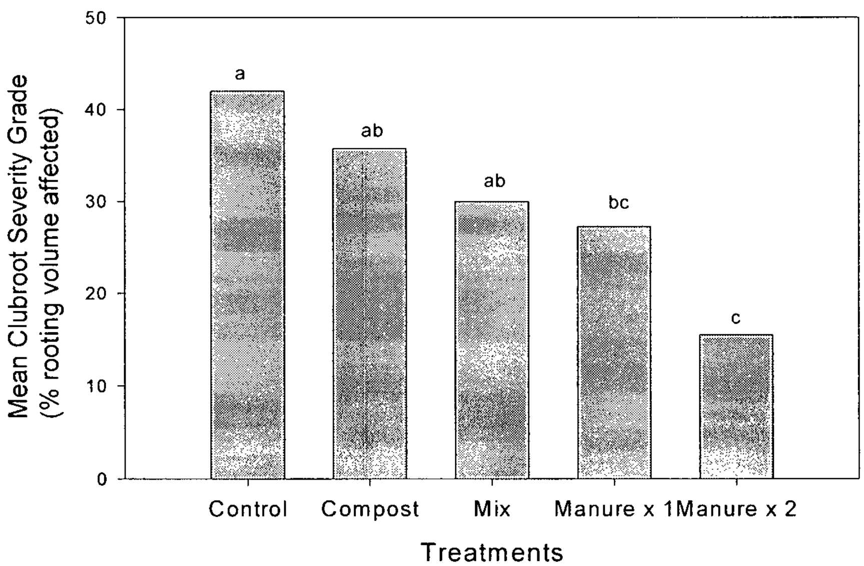

Figure 4.1. Clubroot severity in broccoli as a function of fertilizer treatments.
results with the same letter are not significantly different according to Duncan's multiple range test at $p<0.05$

4.1.2 Beans - Grey Mold and Rhizoctonia Root-Rot Assessment

Grey mold (*Botrytis cinerea*) incidence on bean stems but not on bean leaves, assessed at harvest, was affected by fertilizer treatment (Figure 4.2, Table A.4). However, the very low absolute numbers of stems affected (mean = 1.65 out of about 33 total stems for the treatment with the highest incidence), suggest that grey mold is not a serious threat in this particular field. Crop rotation practices that include corn every third year may be effective in controlling grey mold, since corn is not a host to grey mold fungus (Howard *et al.* 1994).

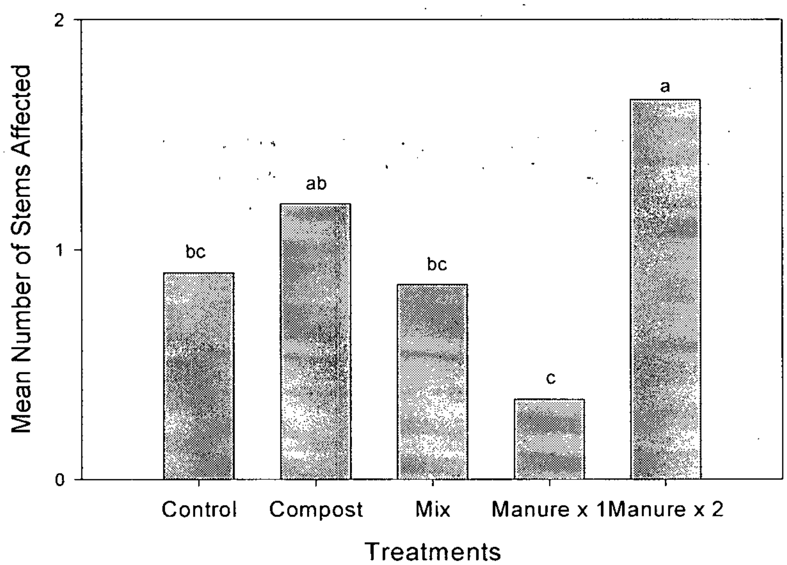

Figure 4.2. Bean stems affected by grey mold as a function of fertilizer treatments.
results with the same letter are not significantly different, according to Duncan's multiple range test, at $p<0.05$

Contrary to the findings of Gorodecki and Hadar (1990), rhizoctonia root rot (*Rhizoctonia solani*) was not affected by organic fertilizer treatments in beans at mid-season or at harvest (Table A.4, Figure A.1). Gorodecki and Hadar (1990) used composed grape marc and composted separated cattle manure as the fertilizer treatments in their experiment, and concluded that the reduced severity was a result of increased microbial diversity due to treatments. The lack of response in this study may be related to different microbial populations of the organic fertilizers used, compared with those of Gorodecki and Hadar (1990), or to the low incidence of rhizoctonia overall. Mean root area affected did not exceed 15% (Figure A.1).

4.1.3 Weeds

The most common weeds found in the corn and bean fields are listed in Table 4.1. None of the weeds showed a response to treatment in frequency or abundant cover in either the corn or the bean field (Tables A.5 - A.8).

Table 4.1. Weed species observed in corn and bean experiments.

Experiment	Latin Name	Common Name
Corn	*Amaranthus retroflexus* L.	redroot pigweed
	Capsella bursa-pastoris L. Medic.	shepherd's purse
	Chenopodium album L.	lambsquarters
	Polygonum convolvulus L.	wild buckwheat
	Polygonum persicaria L.	smartweed
	Senecio sylvaticus L.	wood groundsel
	Stellaria media L. Vill.	chickweed
Beans	*Chenopodium album* L.	lamb's quarters
	Polygonum convolvulus L.	bindweed
	Polygonum persicaria L.	lady's thumb
	Senecio sp. L.	groundsel

The species observed are likely present as a result of the seed bank composition in these fields. With the exception of *Senecio sp.*, which can be wind-dispersed (Mohler 2001) , the weed species observed overwinter on the soil surface (Basset and Crompton 1978, Frankton and Mulligan 1970, Hume *et al.* 1983, Turkington *et al.* 1980, Weaver and McWilliams 1980) and do not disperse far from the mother plant (Mohler 2001). With endemic populations of these weed seeds in the fields, and high residual nutrient levels, differences in weed composition are not likely to occur as a result of a single spring fertilizer application.

The lack of weed response to fertilizer treatments in this study is not sufficient evidence that weed-crop competition is not a problem in Delta due to high rates of fertilizers. The link between nutrient-rich soil environments and crop losses due to weed competition is well-established in the literature (Dyck *et. al.* 1995, Iwata *et. al.* 1980, Okumura *et. al.* 1986). It may be that farmers are expending more effort on weed control than would be necessary if nutrient levels were decreased. Most vegetable fields in Delta, including the experimental site, are hand-cultivated once or twice over the growing season.

A more complete understanding of weed-crop competition could be gained in the future if experimental plots were not hand-cultivated, and if weed biomass and height were measured in addition to the frequency, abundance, and crop yield parameters measured here.

4.1.4 Insects

Green peach aphids (*Myzus persicae*), cabbage aphids (*Brevicoryne brassicae*), and the lepidopterous pests diamondback moth (*Plutella xylostella*) and cabbage looper (*Trichoplusia ni*) were the main pests present on broccoli at the time of sampling. Summed aphid counts and summed lepidopteran counts showed no response to treatments (Table A.3).

Aphid infestation was lower in general in Delta in the 2001 season than the average of previous years.[4] It is possible that greater pest pressure may reveal differences in predation patterns in future years.

4.1.5 Diagnostic Plant Tissue Nitrogen

Every treatment in the corn experiment showed a mean total N concentration within the sufficiency range of 2.8-3.5% given by Fageria *et al.* (1997). The nitrogen contents obtained on manure-treated plots were higher than other treatments, but the two manure treatments did not differ (Tables 4.2., A.9).

All bean treatments were within the 3-6% total N sufficiency range proposed by Mills and Jones (1996). The double rate of manure treatment showed higher tissue N content than all other treatments (Tables 4.2, A.9).

Table 4.2. Total N in corn and bean diagnostic plant samples.

Treatment	Mean Total N of Corn Tissue (%)	Mean total N of Bean Tissue (%)
Control	2.89b	3.68b
Compost	3.09b	3.95b
Mix	3.04b	3.95b
Manure x 1	3.39a	3.79b
Manure x 2	3.39a	4.42a

results with the same letter are not significantly different according to Duncan's multiple range test at $p<0.05$.

Broccoli diagnostic measurements of leaf tissue N at the stage of floret emergence were not available at the time of writing.

Nitrate concentrations of broccoli florets were not affected by treatment (Table A.16, Figure A.2). Within-treatment coefficients of variation ranged from 75% for the control to

[4] Niven, Heather. E.S. Cropconsult. personal communication 2001.

150% for the compost. Four of the values were negative, and the largest negative value was -836 mg NO_3^--N/kg fresh broccoli. Instrumentation readings were accurate only to +/-0.08%.

Seven of the twenty plots showed nitrate concentrations higher than the maximum acceptable level for infants of 900 mg/kg fresh product (Corré and Breimer 1979), and four of these were above the maximum acceptable level for adults of 1200 mg NO_3^-/kg fresh product (Corré and Breimer 1979, Table A.16). The highest level was 1960 mg/kg. However, this measurement could range from 1433 to 2475 within instrumentation error (See Appendix B for a sample calculation).

These data suggest that there may be cause for concern about high levels of nitrate accumulation, but at present this cannot be linked to fertilizer applications nor accurately quantified. This seems largely due to inaccuracy of the macro Kjeldahl method (section 3.3.5). For future NO_3^--N extractions of plant material, the KCl extraction method used by Zebarth *et al.* (1995) may improve accuracy.

4.1.6 Yields

4.1.6.1 Corn

Manure and mix treatments did not affect marketable yields relative to the control (Figure 4.3). Composted yard trimmings reduced marketable yields relative to the double rate of manure (Figure 4.3). The same pattern was observed for the dry weight of the random 3-cob subsample and number of tillers (Table A.10). Corn vegetative biomass and main stalk numbers were not affected by treatment (Table A.10). The advantage to applying manure is not convincing at this point, since control plots performed just as well, at a spreading cost of $0.00.

Farmers measure yields for sweet corn by the case, where one case contains 4 dozen cobs. A yield of about 500-750 cases per hectare is considered satisfactory to farmers,[5] and the 1990-2000 mean provincial yield was 11.1 t/ha (BCMAFF 2002) . The mean cob yields and cob biomass from each treatment are comparable with these values, with the exception of the composted yard trimmings treatment, which is about 60 cases and 3 t/ha below this.

[5] Harris, Brent. Fraserland Organics. personal communication 2002.

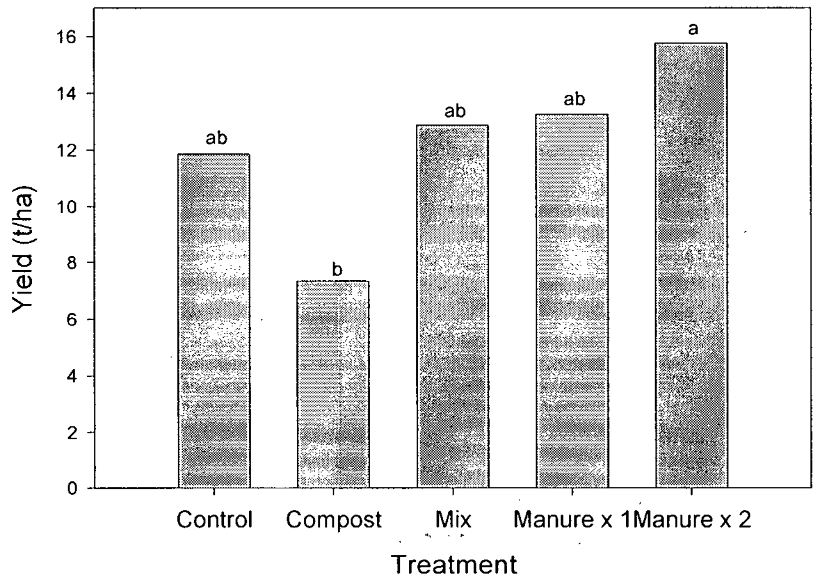

Figure 4.3. Corn marketable yields as a function of fertilizer treatments.
results with the same letter are not significantly different according to Duncan's multiple range test, at $p<0.10$

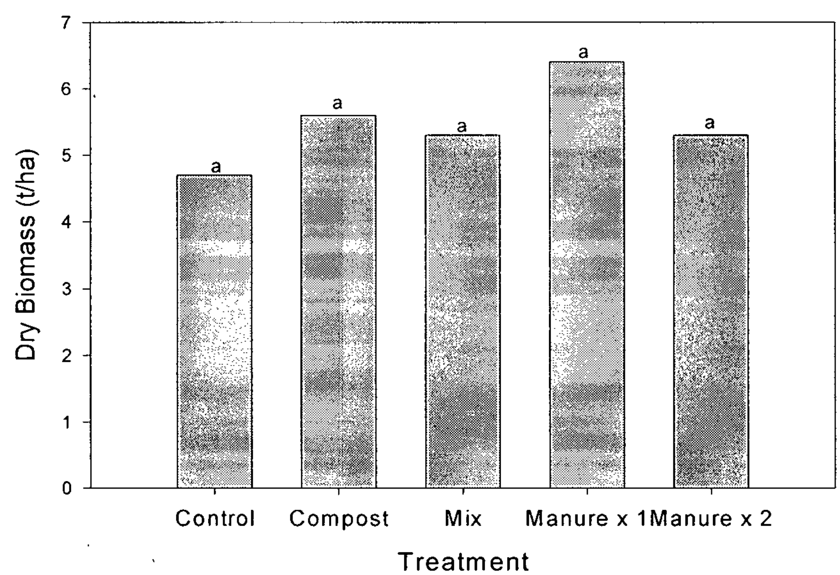

Figure 4.4. Corn dry vegetative biomass as a function of fertilizer treatments
results with the same letter are not significantly different according to Duncan's multiple range test, at $p<0.05$

4.1.6.2 Beans

All treatments yielded the same marketable and vegetative bean biomass, except the single rate of poultry manure which decreased biomass (Figures 4.5 and 4.6, Table A.10). With the same exception, mean marketable yield of all treatments was comparable with the farmers' expectations of about 9-12 t/ha[5], and slightly higher than the 1990-2000 mean provincial yield of 7.2 t/ha (BCMAFF 2002).

The cause of the decline in yields and biomass for the single manure treatment is unknown at present. A negligible number of nodules was found on bean roots in all treatments (Figure A.3), which may be a result of soil nitrogen levels being high enough to suppress nodulation (Brady and Weil 1999). Thus, a nitrogen deficiency was unlikely to have been the cause of lower yields of this treatment. Because the double rate of manure did not decrease yields, nitrogen excess is also an unlikely cause. The fact that all diagnostic tissue samples are within the sufficiency range supports this statement (Table 4.2).

The incidence of grey mold on stems (Figure 4.2) roughly follows the same pattern as yields, with higher-yielding plots showing higher infection for all treatments except the control. Grey mold is usually omnipresent as airborne spores, and thrives on plants that provide a humid microclimate with poor air circulation (Howard *et al.* 1994). The observed relationship could be due to the increased vegetative biomass providing a denser canopy, which would favour fungal growth on the plant surface. Thus, high rates of nitrogen application to beans may be linked to grey mold infection indirectly by causing more vegetative growth, but these data suggest that this did not pose a concern for yields in this field in 2001.

[5] Harris, Brent. Fraserland Organics. personal communication 2002.

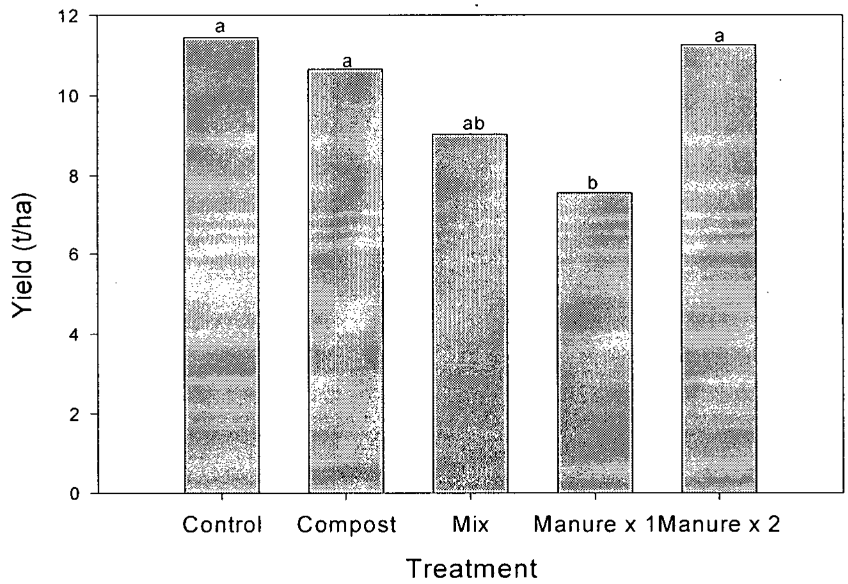

Figure 4.5. Bean marketable yields as a function of fertilizer treatments.
results with the same letter are not significantly different according to Duncan's multiple range test, at p<0.05

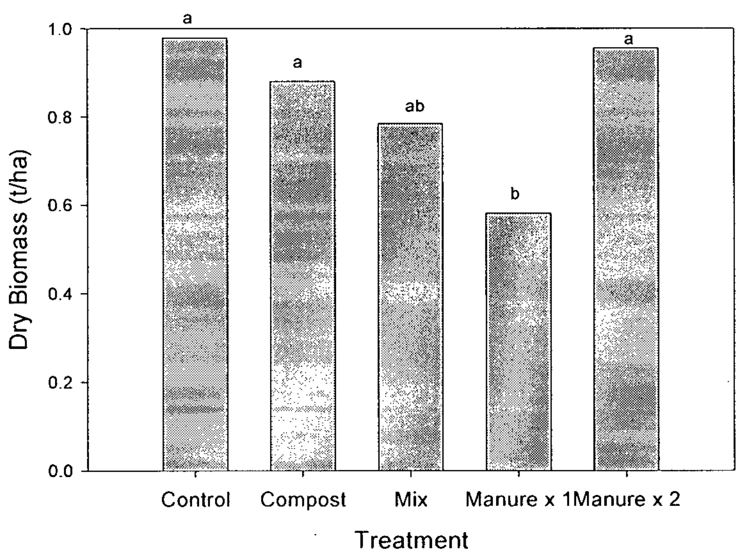

Figure 4.6. Bean dry vegetative biomass as a function of fertilizer treatments.
results with the same letter are not significantly different according to Duncan's multiple range test, at p<0.05

4.1.6.3 Broccoli

Broccoli marketable yields and vegetative biomass were not affected by treatment, (Figure 4.7, Table A.10). Farmers expect 6-12 t/ha from a broccoli crop[5] and the 1990-2000 mean provincial yield for broccoli was 6.8 t/ha (BCMAFF 2002). The mean yield of our experimental plots was approximately 4 t/ha. Eighty-five percent of the florets were below 10 cm in diameter at the time of harvest, where a head of at least 7.5 cm in diameter is marketable.

Furthermore, yields in this study were about five times lower than those found by Zebarth *et al.* (1995) in Agassiz, B.C. In that study, marketable yields of 10-15 t/ha were recorded in control plots, with comparable planting and harvesting dates and planting density to this experiment, although the variety was different. These comparisons suggest that broccoli yield was limited in this study, which may be the result of clubroot presence in the field.

It should be noted that the suppression of clubroot by the double rate of poultry manure (Figure 4.1) was not sufficient to raise yields (Figure 4.7).

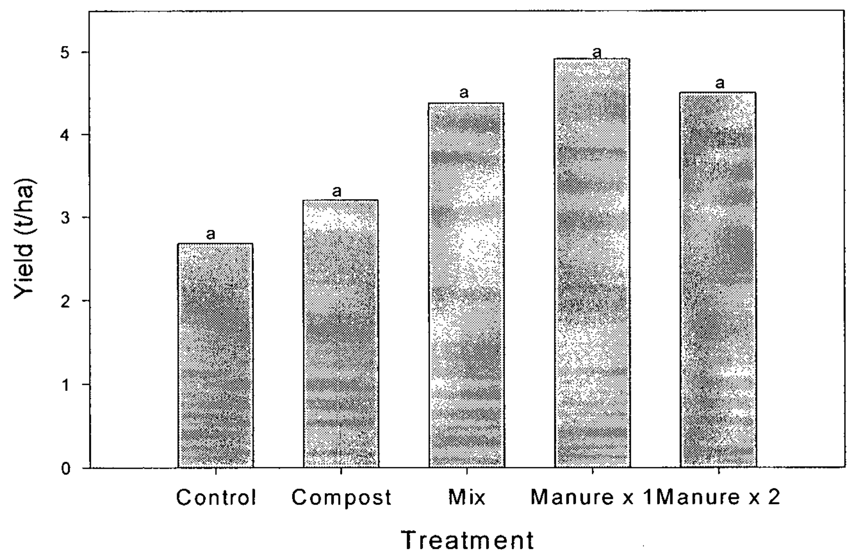

Figure 4.7. Broccoli marketable yield as a function of fertilizer treatments.
results with the same letter are not significantly different, according to Duncan's multiple range test, at $p<0.05$.

[5] Harris, Brent. Fraserland Organics. personal communication 2002.

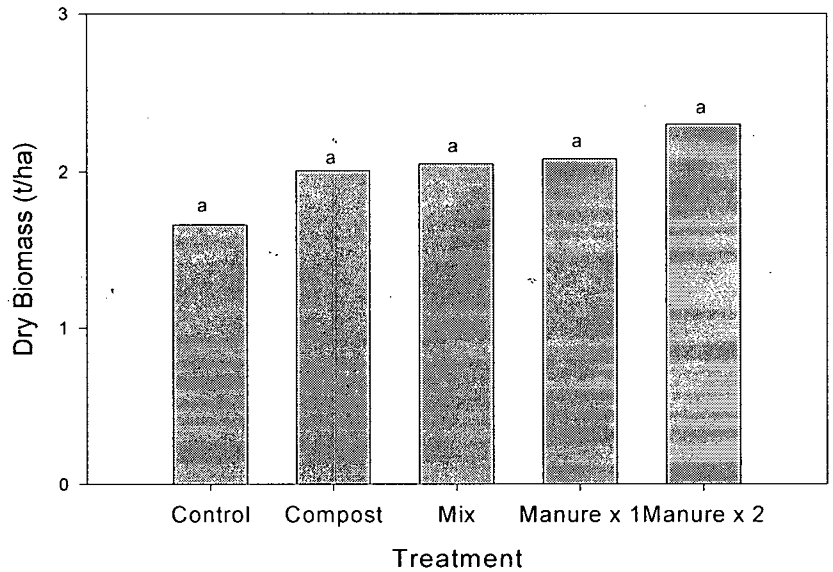

Figure 4.8. Broccoli dry vegetative biomass as a function of fertilizer treatments. results with the same letter are not significantly different, according to Duncan's multiple range test, at $p<0.05$.

4.2 Potential for Nitrate Leaching

4.2.1 Autumn Soil Nitrate Levels

Treatment had an effect on the residual soil nitrate in autumn in the corn and broccoli fields, but not in the bean field (Table A.11). In the corn (Figure 4.9) and broccoli fields (Figure 4.10), the double rate of poultry manure showed the highest levels of autumn soil nitrate. In both fields, the mean autumn soil nitrate levels in the plots treated with the double rate of manure were approximately three times higher than the plots treated with the single rate of manure, even though the application rate was only doubled. Although the same pattern among treatments was observed for both experiments, the double manure treatment in broccoli showed a level of about 140 kg/ha, and in the corn experiment it was only 60 kg N/ha.

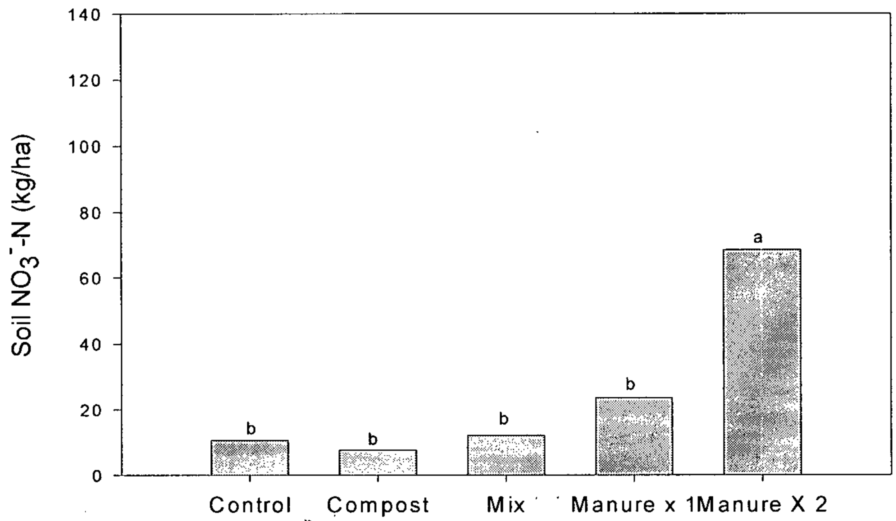

Figure 4.9. Autumn soil NO_3^--N in corn plots treated with organic fertilizers.
results with the same letter are not significantly different according to Duncan's multiple range test at $p<0.05$

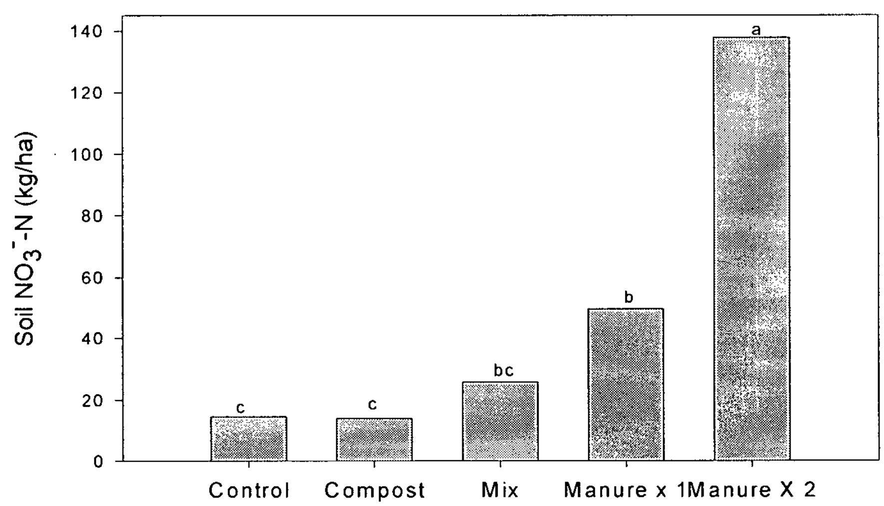

Figure 4.10. Autumn soil NO_3^--N in broccoli plots treated with organic fertilizers.
results with the same letter are not significantly different according to Duncan's multiple range test at $p<0.05$

In the bean field, the lack of treatment effects on soil residual nitrogen in autumn (Figure 4.13) appears to be related to the sequestration of mineral nitrogen by the barley cover crop and possible leaching of nitrate in October. Soil samples taken in the bean field (Figure 4.11) on July 26, 2001 showed the same pattern as the autumn sampling for the corn and broccoli fields (Figures 4.9 and 4.10), with the double manure treatment showing disproportionately high levels of nitrate.

The N uptake by the cover crop, which occurred from August 28, 2001 (planting date) to November 3, 2001 (sampling date) was uniform across treatments at about 100 kg/ha (Figure 4.12, Table A.12). This was around the maximum N uptake found by Nafuma (1998) in Delta in November samplings of spring barley and winter rye cover crops. This comparison indicates that the cover crop in this study was taking up as much nitrogen as can be expected in Delta.

In all treatments except the double rate of manure, the cover crop N-uptake (Figure 4.12) is about 80 kg/ha higher than the soil mineral nitrogen in July (Figure 4.11), about two weeks before harvest. This indicates that post-harvest nitrogen mineralization must have occurred in order to provide the cover crop with 100 kg N/ha.

Assuming a uniform post-harvest mineralization rate among treatments[6], the autumn nitrate levels in the double manure treatment would be much higher than the amount taken up by the cover crop, which would result in high residual N in autumn in these plots. However, this was not observed in the November sampling (Figure 4.13). Rainfall in October was 111.6 compared with a long-term mean of 86.3 mm (Figure 3.5), hence leaching of some post-harvest nitrate may have occurred in these plots before it could be measured.

Although inconclusive, these data warn that even the use of a cover crop may not be sufficient to prevent nitrate leaching at very high soil nitrogen levels in the humid climate of Delta. In the case of the barley cover crop following a bean crop, N application rates above those delivered by the single pass of the spreader may be in excess of the summed N uptakes of the bean crop and the cover crop.

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[6] Table A.14 shows that crude mineralization rates for all treatments (measured as (soil NO_3^--N + crop N at harvest - control plots)/total fertilizer N applied x 100) except the compost were equal. However, substantial variation occured within treatments, and many values were negative, relative to controls. This suggests that not all nitrogen in the bean treatments can be accounted for by the measurements taken.

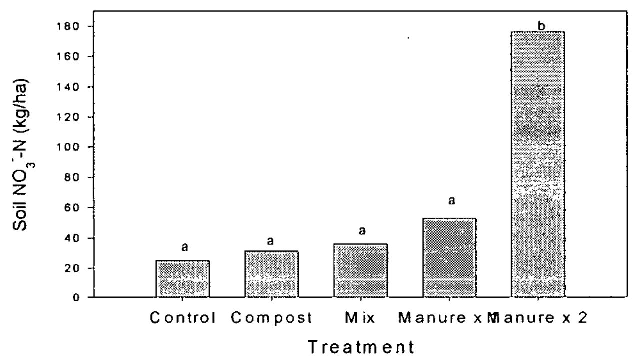

Figure 4.11. Soil nitrate levels in bean field, July 26, 2001, 2 weeks before harvest.
results with the same letter are not significantly different, according to Duncan's multiple range test, at $p<0.05$

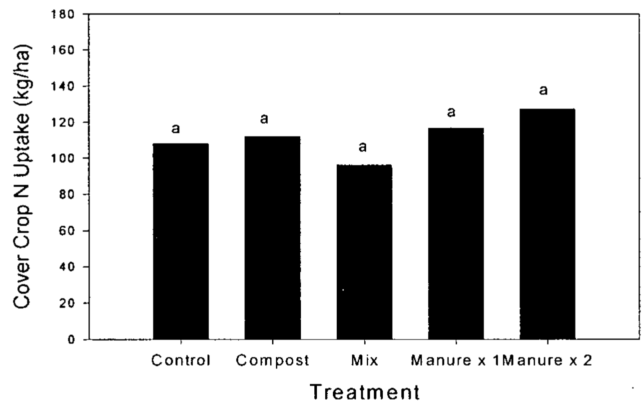

Figure 4.12. Nitrogen uptake by barley cover crop, planted August 2001 following beans
results with the same letter are not significantly different, according to Duncan's multiple range test, at $p<0.05$

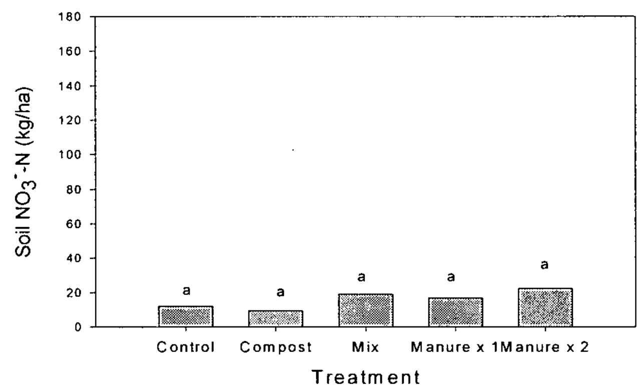

Figure 4.13. Soil nitrate levels in bean field, November 3, 2001.
results with the same letter are not significantly different, according to Duncan's multiple range test, at $p<0.05$

4.3 Predicting Appropriate Manure Application Rates

4.3.1 Available Soil N

In the three field experiments, control plots show that there is a large pool of available soil N (Table 4.3), which is likely a result of previous manure applications (Pratt *et al.* 1973, Pang and Letey 2000, Carpenter-Boggs *et al.* 2000) and cover cropping (Vyn *et al.* 1999) in the case of the corn and bean fields. This explains the lack of yield difference between manured plots and control plots in all experiments, and underscores the need to consider available soil N pools before applying fertilizer inputs.

Table 4.3. Available soil N (soil mineral N + crop N at harvest) in corn, bean and broccoli experiments.

Experiment	Mean Mineral N of Control (kg/ha)	% of Initial Soil N mineralized
Corn	117	3.3
Beans	115	3.1
Broccoli	89	3.5

Quantifying the capacity of poultry manure and composted yard trimmings to contribute to mineralizable soil nitrogen over several seasons in Delta would help farmers to better understand the nitrogen-supply capability of their soil and have the confidence to reduce inputs.

Experiments carried out in California on sandy soils have shown that about 90% of poultry manure nitrogen is mineralized over the course of one year (Pratt *et al.* 1973). However, in soil environments with a greater clay content (Gordillo and Cabrera 1997b), such as the silt loam of Delta, mineralization will be slower.

The broccoli experiment in this study offers the longest-term look at the nitrogen mineralized over the season, with about 120 days between manure spreading and total mineral nitrogen measurement of treatments. The manure treatments in the broccoli experiment showed a range of 27% to 86% of fertilizer nitrogen mineralized, with a mean of 46% (Table A.13, A.14). Even if a portion of the remaining 54% is stored as mineralizable N, it is possible that over time, the residual nitrogen accumulated in soil from manure applications could be significant, although variable. The observation of high available soil N levels in all plots may be suggestive of this effect, reflecting the continous manure application of the last few years, and cover cropping in the case of the corn and bean plots.

The capacity of composted yard trimmings to contribute to soil mineralizable N and organic matter is also relevant and should be investigated in Delta. Experiments on loam and clay loam soils of Ontario suggest that composted yard trimmings, applied regularly to soil, will reduce the need for P and K but not N applications in the spring (Alder *et al.* 1997). Pearson *et al.* (1998) found that on silt loam soils, a single application of composted yard trimmings at a rate of 50 t/ha did not increase soil organic C measurements from controls, but a rate of 300 t/ha did cause an increase between the time before application and the time of harvest in the same growing season. Alder *et al.* (1997) found that it took three successive years of applications of 100 t/ha to significantly increase soil organic matter on loam and clay loam soils in southwestern Ontario. Based on these findings, it seems likely that a very high input of compost may be required in order to increase organic matter in Delta, and that it will not become a source of available soil N.

4.3.2 Crop Nitrogen Uptake

4.3.2.1 Corn

Total crop uptake for sweet corn seemed to increase curvilinearly with N application rate (Figure 4.14). Although variable, the uptake does not exceed 140 kg N/ha on average. Kowalenko and Hall (1987) found a similar maximum uptake (142 kg N/ha) in sweet corn treated with 250 kg mineral N/ha in Agassiz, B.C. The highest nitrogen application did not result in the highest crop uptake, which explains why there is a substantially higher soil nitrate in autumn for the double manure treatment. Figure 4.14 shows that N-uptake efficiency decreased above organic fertilizer applications of about 400 kg N/ha (shown by the decrease in the slope after this point).

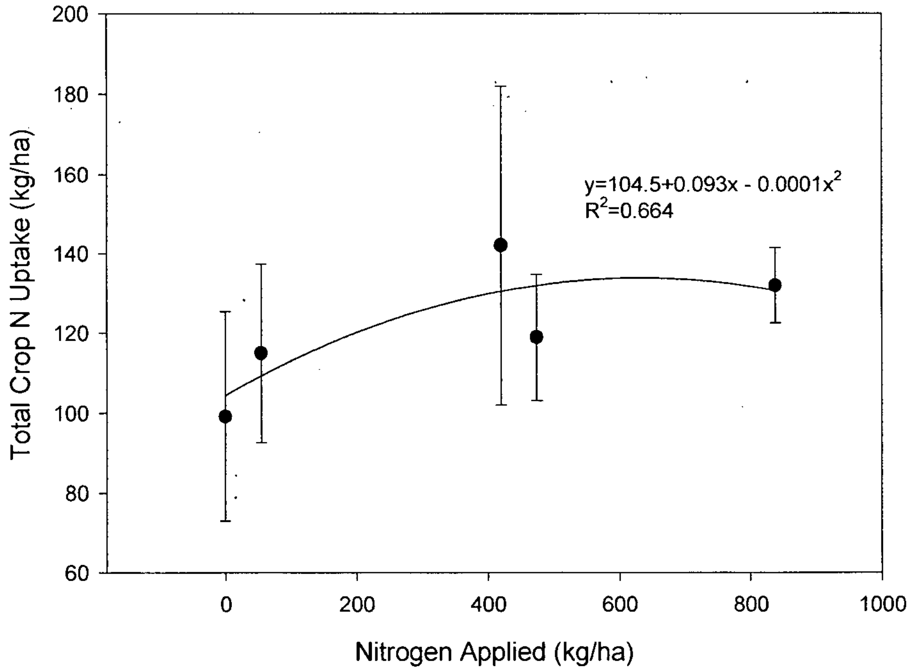

Figure 4.14. Corn N uptake as a function of nitrogen applied by organic fertilizers.
error bars show +/- one standard deviation about the mean, n=4

4.3.2.2 Beans

The crop-uptake curve for beans offered no estimate of maximum uptake efficiency (Figure A.4).

4.3.2.3 Broccoli

The total nitrogen uptake of the broccoli crop increased curvilinearly with the total nitrogen applied (Figure 4.15). This figure excludes data from the compost treatments, as compost showed a different mineralization rate from all other treatments (Table A.13, A.14).

Although the mathematical maximum for N-uptake on this curve is near the highest rates of application, the efficiency with which nitrogen is taken up by broccoli decreases starting at approximately 350 kg N/ha (shown by the decrease in the slope after this point) which is equivalent to the single pass of manure treatment. The disproportionately high levels of residual soil nitrate in the double manure treatment (Figure 4.10) reflect that the maximum crop uptake had been exceeded.

The maximum whole-plant nitrogen uptake was reached at about 110 kg/ha, compared with 450 kg N/ha observed by Zebarth *et al.* (1995), which suggests that potential nitrogen uptake was lower in this crop and may be the cause of the lower yields observed in this study. While it is possible that the presence of clubroot was the cause of the lower N-uptake and yields, the double manure treatment did not suppress clubroot enough to bring yields up or to encourage nitrogen uptake.

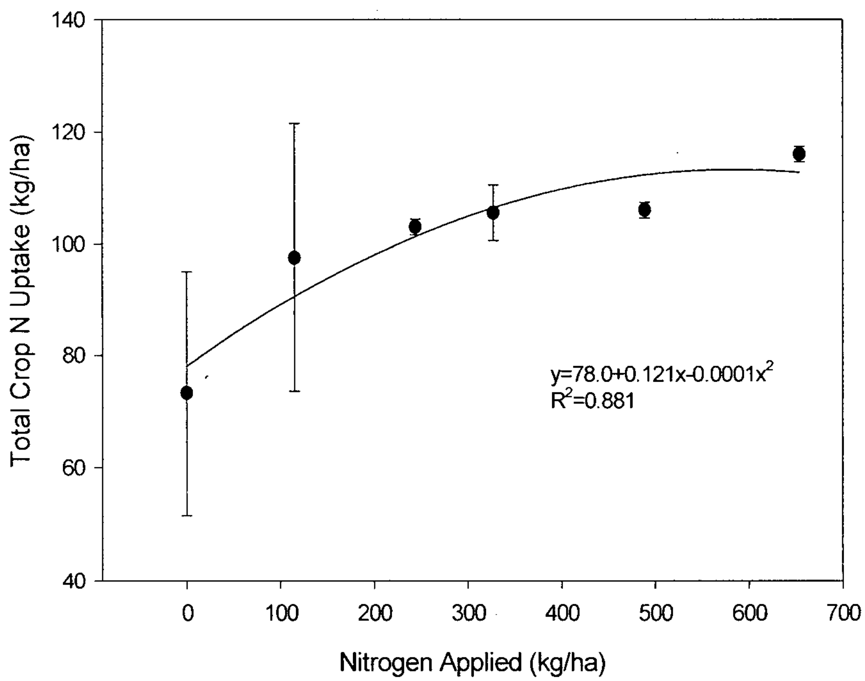

Figure 4.15. Broccoli N uptake as a function of nitrogen applied by organic fertilizers.
error bars show +/- one standard deviation about the mean, n = 4

4.3.3 Potentially Mineralizable Nitrogen from Two Poultry Manure Rates

The preliminary chemical analyses of all the manure samples are presented in Table 4.4. Of note is the low variability of the total nitrogen, since such uniformity is not common in the literature. Bitzer and Sims (1988) found a range of 18 to 81 g N/kg dry litter in 20 samples collected from broiler barns and stockpiles. Gordillo and Cabrera (1997a) found a range of 26.8 to 59.6 g N/kg dry litter (cv = 21%) in 15 samples collected from broiler barns in Northern Georgia. Qafoku *et al.* (2001) found a range of 23.8 to 47.0 g N/kg dry litter in 99 samples collected from broiler barns in Georgia and South Carolina.

Table 4.4. Chemical characteristics of 20 poultry manure piles in Delta.

Statistics	Total C (%)	Total N*	C:N	NH_4^{+*}	NO_3^{-*}	Moisture (%)	Density (g/cm^3)
Mean	45.8	46	9.5	4.9	0.34	30.0	0.30
SD	2.8	5	1.3	2.1	0.75	6.0	0.04
C.V.	6.4%	9.9%	13.6%	43.9%	21.7%	23.8%	15.1%

* g/kg dry manure

The uniformity in this study likely indicates that there exists common feeding and stocking practices among poultry producers who deliver their manure to Delta. If this continues to be the case in this region, the task of predicting manure application rates may be slightly easier, as it will be feasible to assume an average total nitrogen concentration for manure stockpiled in the area. The greater challenge is predicting mineralization rates under Delta conditions.

Mineralized nitrogen over 30 days in the laboratory exhibited higher variability than total nitrogen, with coefficients of variation in the 25-30% range (Table 4.5). Attempts have been made in the past to correlate manure chemical characteristics with results of incubation experiments (Bitzer and Sims 1988, Castellanos and Pratt, 1981, Gordillo and Cabrera 1997a, Qafoku *et al.* 2001, Serna and Pomares 1990). Strong correlations provide a means of predicting the potentially mineralizable nitrogen of a specific manure source, based on a variable which can be measured rapidly in the lab. Table 4.6 shows the results of simple linear regressions using total N, C:N and initial NH_4^+ of the manure as independent variables. While several of these relationships are statistically significant, the amount of variability predicted by the independent variables (represented by r^2) does not approach those found in the literature (Bitzer and Sims 1988, Castellanos and Pratt, 1981, Gordillo and Cabrera 1997a, Qafoku *et al.* 2001, Serna and Pomares 1990).

Table 4.5. Mineral N at 31 and 74 days in incubation of 20 manure samples at two application rates.

Rate	31 days			74 days		
	Mean NO_3^--N	Mean %*	C.V.	Mean NO_3^--N	Mean %*	C.V.
10 t/ha	61.3 mg/kg soil (147.1 kg/ha)	36.3	26.4%	67.5 mg/kg soil (162 kg/ha)	39.9	27.3%
5 t/ha	30.3 mg/kg soil (72.2 kg/ha)	35.5	24.2%	36.5 mg/kg soil (87.6 kg/ha)	42.8	29.0%

* % of total N present as mineral N, averaged for all 20 pots

Table 4.6. Coefficients of determination (r^2) for the regression of three independent variables against manure NO_3^--N in an incubation experiment.

Independent Variable	31 days		74 days	
	10 t/ha	5 t/ha	10 t/ha	5 t/ha
Total N	0.302*	0.426*	0.148	0.423*
C:N	0.194	0.307*	0.226*	0.281*
NH_4^+	0.010	0.028	0.148	0.085

*significant at $p<0.05$

Variation in field application rates within and among fields dictates the degree of precision that is useful to farmers. In this study, variation observed in all the replicated measurements of the single manure treatment in the field was 40% (Table A.15). This is greater than the variability of under 30% found in the lab experiment (Table 4.5). Therefore, searching for precise predictors of mineralization rates of specific manure sources is not likely to improve farmers' ability to apply manure at appropriate rates. Rather, replicating the manure survey in subsequent years can establish whether the total nitrogen remains relatively constant between seasons, and if so, an assumed total N value could be established for future use. The mean percentage of total N measured as mineral N in this incubation study may be used as a rough guideline for predicting the amount of available N that will be contributed by a manure application.

4.3.4 Potentially Mineralizable Nitrogen from Mixtures of Composted Yard Trimmings and Poultry Manure

Composted yard trimmings, when added to poultry manure in increasing proportions, reduced the nitrate mineralized after 30 and 61 days according to linear equations (Figure 4.16).

After 30 days, each of the four incubation pots containing only composted yard trimmings showed a small amount of immobilization, with a mean of -0.7 mg NO_3^--N/kg soil, relative to the controls. After 61 days, mineralization had begun, but only 2.5 mg NO_3^--N/kg soil was available by this time, relative to the controls.

These findings may serve as a tool for predicting a ratio that will deliver appropriate levels of nitrogen. Data indicate that 100% poultry manure at about $25m^3$/ha, about one pass of the spreader, can potentially provide about 140 kg NO_3^--N/ha after 30 days, and or 170 kg NO_3^--N/ha after 61 days, over and above mineral N provided by the soil. For crops with lower nitrogen needs such as pulses and grains, mixing yard trimmings with manure could adjust the nitrogen application rate to meet crop demand. Knowing the nitrogen requirement of a crop in kg/ha, data from Figure 4.16 could be used to predict the ratio of manure to composted yard trimmings that would deliver mineral nitrogen in an amount suited to crop needs.

One complicating factor in the use of this chart as a predictive tool is the initial soil nitrogen of the field, which will vary among fields depending on crop rotation and fertilization history. This could alter the need for nitrogen inputs at the beginning of the season and complicate this prediction method. Fields which are exposed to rotations that include a legume, and/or organic fertilizers (i.e. most fields where organic production occurs in this region), may require less nitrogen input than other fields (Carpenter-Boggs *et al.* 2000), and this requirement may decrease over time if such practices continue (Pang and Letey 2000).

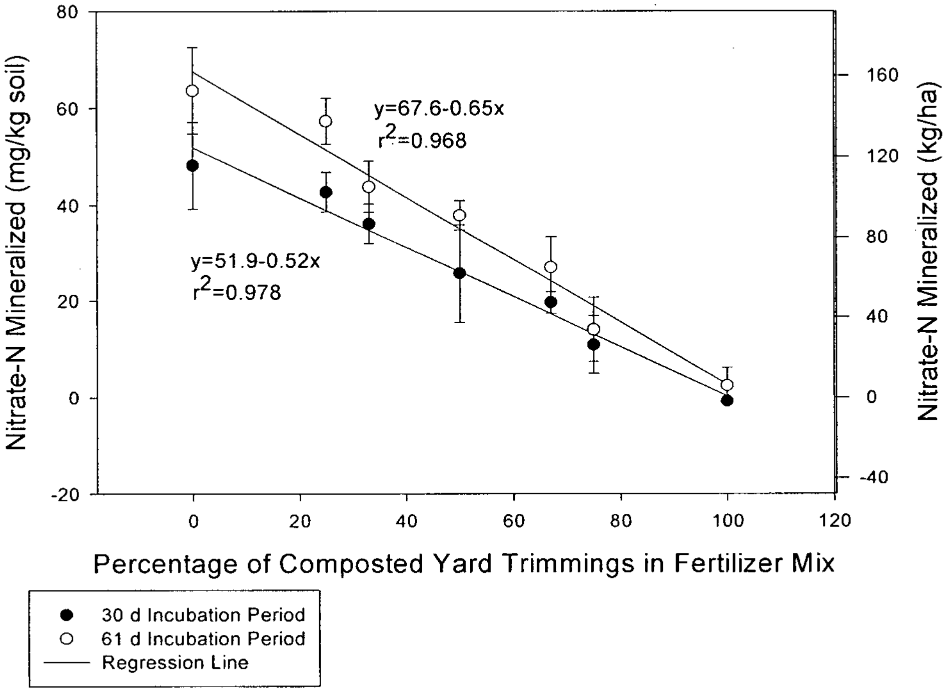

Figure 4.16. Nitrate-N after 30d and 61d vs. composted yard trimmings: poultry manure ratio of fertilizer mix at simulated rate of $25m^3$/ha.

error bars represent +/- one standard deviation about the mean, n = 4

5. Conclusions and Recommendations

5.1 Conclusions

The three crops studied have different nitrogen requirements, from low demand for beans (Fageria *et al.* 1997) to high requirements for corn (Fageria *et al.* 1997) and broccoli, which can be a nitrogen accumulator (Bowen *et al.* 1999). However, similar responses to treatments were observed for all three crops. While no major disadvantage was observed in the crop quality parameters assessed (weeds, pests, diseases, tissue nitrogen and yields), no advantage was apparent in applying any of the tested organic fertilizer treatments. A major disadvantage was that the double rate of manure caused high levels of soil residual N in November. In the corn and broccoli fields, these high residual N levels were directly observed. In the bean field, the barley cover crop sequestered some of this residual nitrogen. However, the double rate of manure seemed to provide nitrogen that was in excess of the summed N-uptakes of bean and barley crops.

It seems that the high residual N levels in corn and broccoli experiments were a result of application rates exceeding the maximum crop N-uptake. Broccoli took up a maximum of about 110 kg N/ha, even at the highest manure application rate, and corn took up less than 140 kg N/ha.

Incubation results showed that within 31 days, manure can potentially mineralize levels of nitrogen comparable to uptake observed in the field, at a rate of approximately 10 t/ha, or 25 m^3/ha. Therefore, with negligible soil mineral N contribution, manure applications at this rate could be sufficient for sweet corn crops, and for broccoli with a maximum N-uptake similar to that found in this study. However, soil mineral N levels were not negligible, and approached levels sufficient to support high-demand crops in all fields studied.

All of these results suggest that manure application rates in Delta can be decreased without detriment to crop quality. Field and laboratory results agree that a rate of 10 t/ha should provide sufficient nitrogen to high-demand crops, without causing excessive leaching. However, farmers can reduce their costs and further prevent N leaching losses by (i) considering available soil N pools as a significant contributor to crop N needs, and (ii) reducing soil N levels to the point where nodulation of legumes occurs.

Given the above, there are four possible tools that emerge from this study for predicting appropriate application rates for the crops studied.

1. **Estimates of mineralization rates in the laboratory and field.** In the lab it was found that manure sources can potentially mineralize about 40% of the total N within 74 days, including initial mineral N. This finding seemed to be a reasonable approximation of the N-mineralization of manure in the broccoli field experiment (46%), and could be used to give farmers a rough idea of the N-supply capability of manure sources at specific rates.

2. **Use of composted yard trimmings to adjust nitrogen application rates.** This experiment showed that composted yard trimmings reliably decrease the N mineralized from a fertilizer mix when combined with manure. The graph generated (Fig 4.16) could be used to determine an appropriate manure:compost mix for specific crops at the minimum application rate of 25 m^3/ha. At this rate, 100% manure provides sufficient mineral N for crops with high N requirements like corn and broccoli, on soils that provide very little mineral N.

3. **Crop N-uptake curves.** Both broccoli and corn experiments provided uptake curves which showed an estimate of maximum crop uptake (110 and 140 kg N/ha, respectively) at a manure application rate of about 10 t/ha or 25 m^3/ha.

4. **Soil initial nitrogen levels and mineralizable pool inferred from management history.** This study gives evidence that available soil nitrogen is a significant contributor to the nitrogen budget of the system, and must be taken into account before inputs are added.

5.2 Recommendations

For farmers in Delta:

- A large pool of soil mineralizable N exists in the fields studied, which is reaching levels sufficient for supporting sweet corn and broccoli crops with limited N-uptake. All other nutrients measured show very high levels. These soil levels should be inferred from management hisory and manure should only be added where a nutrient deficiency is predictable.

- Under current management practices, the soil provides enough mineral nitrogen to inhibit nodulation on legumes. Therefore, the potential for legumes to contribute to soil N is untapped. Encouraging nodulation may be a cost-effective way to maintain available N in the system.

- For crops with N-uptakes similar to those observed in this study, a rate of approximately 10 t/ha (25 m^3/ha) of poultry manure should become the new maximum rate, rather than the minimum rate, as it has been used to date. This rate should be used only when soil N levels are low. The risk of nitrate leaching increases disproportionately above this rate.

- Composted yard trimmings can adjust the nitrogen application rate when mixed with manure while potentially contributing to soil organic matter.

To improve the understanding of crop quality :

- Further experiments on sweet corn and beans using the improved experimental design may clarify the nitrogen dynamics and yield response of these crops to organic fertilizers. More accurate measurements of field application rates and minimizing soil compaction are benefits of this improved design.

- Studying broccoli yields on fields not infected with clubroot can show whether this was the cause of the low yields for the 2001 trials, and either support or negate the lack of yield response to high manure inputs.

- Diagnostic measurements for nutrients other than N should be measured. With inherently high soil nutrient levels, and the possible accumulation of nutrients in soil because of manure applications, excesses of other nutrients, particularly P, is a real possibility in the future.

To improve the understanding of nitrate leaching in Delta:

- Determine critical soil residual nitrate levels that would impair water quality.

To strengthen and augment the predictive tools established here:

- Repeat the survey of chemical characteristics of manure piles throughout Delta in subsequent years to determine the reliability of total N measurements in space and time.

- Study the effects of poultry manure and composted yard trimmings applications over time on soil mineralizable N, and establish how these differences may affect the ability to predict N input needs.
- Establish reliable crop uptake curves for other common crops in Delta, which show the manure application rate that results in maximum crop N uptake.

References

Agriculture Canada. May - August 1983. Heavy applications of nitrogen fertilizers increase broccoli yields. Research Review - Research Station, Agassiz, B.C.

Ahmed, M.A., Saleh, E.A. and El-Fallal, A.A. 1994. The role of biofertilizers in suppression of Rhizoctonia root-rot disease of broad bean. Annals of Agricultural Science (Cairo) 39: 379-395.

Alder, V., Sheard, R.W., Kachanoski, R.G., Goss, M.J. 1997. Application of composted organic waste to agricultural land. Canada-Ontario Agriculture Green Plan, COESA Report No. RES/MAN-006/97 http://res2.agr.ca/initiatives/manurenet/env_prog/gp/gpres/report/rep16sum.html.

Anonymous. 2002. Poultry Associations Lead Development of Environmental Strategic Plan. Sustainable Poultry Farming Group Newsletter 9:1-6.

Anonymous. 2000. Groundwater Protection Program Reaches New High. Sustainable Poultry Farming Group Newsletter 7:1-3.

Baldock, J.O. and Schulte, E.E. 1996. Plant analysis with standardized scores combines DRIS and sufficiency range approaches for corn. Agronomy Journal 88:448-456.

Basset, I.J. and Crompton, C.W. 1978. The biology of Canadian Weeds, 32. *Chenopodium album* L. Canadian Journal of Plant Science 58:1061-1072.

Bitzer, C.C. and Sims, J.T. 1988. Estimating the availability of nitrogen in poultry manure through laboratory and field studies. Journal of Environmental Quality 17:47-54.

Brady, N.C. and Weil, R.R. 1999. The Nature and Properties of Soils. 12th ed. Prentice Hall. New Jersey.

Bowen, P.A., Zebarth, B.J. and Toivonen, P.M.A. 1999. Dynamics of nitrogen and dry-matter partitioning and accumulation in broccoli (*Brassica oleracea* var. *italica*) in relation to extractable soil inorganic nitrogen. Canadian Journal of Plant Science 79:277-286.

Bomke, A. A. Yu, S. Temple, W. D. 1994. Winter wheat growth and nitrogen demand in south coastal British Columbia. Canadian Journal of Soil Science 74:443-451.

Bremner, J.M. and Mulvaney, C.S. 1982. Nitrogen -Total. In A.L. Page, R.H. Miller, and D.R. Kennedy (Eds.) Methods of Soil Analysis. Part 2. 2nd Ed. Agronomy Monogr. 9. ASA-SSSA. Madison, WI. pp 595-624.

Bremner, J.M. 1965. Total Nitrogen. In C.A. Black (Ed.). Methods of Soil Analysis Part 2. Chemical and Microbiological Properties. American Society of Agronomy, Inc. Madison, WI. pp 1149-1178.

British Columbia Ministry of Agriculture, Food and Fisheries (BCMAFF). 2002. B.C. Vegetable Statistics. http://www.agf.gov.bc.ca/stats/vegetables/index.htm.

Carpenter-Boggs, L., Pikul, J.L. Jr., Vigil, M.F., Riedel, W.E. 2000. Soil nitrogen mineralization influenced by crop rotation and nitrogen fertilization. Soil Science Society of America Journal 64:2038-2045.

Castellanos, J.Z. and Pratt, P.F. 1981. Mineralization of manure nitrogen - correlation with laboratory indexes. Soil Science Society of America Journal 45:354-357.

Cerrato, M.E. and Blackmer, A.M. 1990. Comparison of models for describing corn yield response to nitrogen fertilizer. Agronomy Journal 82:138-143.

Chipperfield, K. 1996. Demonstration of novel, cost-effective and environmentally friendly approaches to handling and transporting poultry manure to distant markets. Prepared for Environment Canada Environmental Protection, Fraser Pollution Abatement. DOE FRAP 1996-04.

Chipperfield, K. 1994. Sustainable Poultry Farming Group Final Report and Resource Binder 1991-1994. Canada-British Columbia Soil and Water Conservation Program, Project #SCP 1109.

Coody, L. S. 1998. Oregon Tilth Certification Standards and Procedures Manual. http://www.tilth.org/CERTclasses.html

Corré, W.J. and Breimer, T. 1979. Nitrate and Nitrite in Vegetables. Centre for Agricultural Publishing and Documentation, Wageningen.

Dixon, G.R., Naiki, T., Webster, A., Wilson, F. 1987. Integrated use of boron, calcium cyanamide and nitrogen for control of clubroot (*Plasmodiophora brassicae*). Crop Protection in Northern Britain. Proceedings of a Conference held at the Scottish Crop Research Institute, Dundee, UK. 399-404.

Dixon, G.R. and Robinson, D.L. 1986. The susceptibility of *Brassica oleracea* cultivars to *Plasmodiophora brassicae* (clubroot). Plant Pathology 35:101-107.

Dow, A.I. 1980. Critical nutrient ranges in Northwest crops. Washington State University, Western Regional Extension Publication 43.

Dyck, E., Liebman, M., Erich, M.S. 1995. Crop-weed interference as influences by a leguminous or synthetic fertilizer nitrogen source: I. Doublecropping experiments with crimson clover, sweet corn, and lamb's quarters. Agriculture Ecosystems and Environment 56:93- 108.

Everaarts, A.P. and Booij, R. 2000. The effect of nitrogen application on nitrogen utilization by white cabbage (*Brassica oleracea* var. *capitata*) and on nitrogen in the soil at harvest. Journal of Horticultural Science and Biotechnology 75:705-712.

Fageria, N.K., Baligar, V.C., Jones, C.A. 1997. Growth and Mineral Nutrition of Field Crops. 2nd ed, Revised and Expanded. Marcel Dekker, Inc. New York.

Fan, A.M. and Steinberg, V.E. 1996. Health implications of nitrate and nitrite in drinking water: an update on methemoglobinemia occurrence and reproductive and developmental toxicity. Regulatory Toxicology and Pharmacology 23:35-43.

Frankton, C. and Mulligan, G.A. 1970. Weeds of Canada. Canada Department of Agriculture. Publication 948.

Fraser Basin Council, 2001. Nutrient Management Planning Strategies for the Fraser Valley: Report of the Nutrient Managment Action Plan Working Group of the Partnership Committee on Agriculture and the Environment.

Gale, P.M. and Gilmour, J.T. 1986. Carbon and nitrogen mineralization dynamics for broiler litter. Journal of Environmental Quality 15:423-426.

Gordillo, R.M. and Cabrera, M.L. 1997a. Mineralizable nitrogen in broiler litter: I. Effect of selected litter characteristics. Journal of Environmental Quality 26:1672-1679.

Gordillo, R.M. and Cabrera, M.L. 1997b. Mineralizable nitrogen in broiler litter: II. Effect of selected soil characteristics. Journal of Environmental Quality 26:1679-1686.

Gorodecki, B. and Hadar. Y. 1990. Suppression of *Rhizoctonia solani* and *Sclerotium rolfsii* diseases in container media containing composted separated cattle manure and composted grape marc. Crop Protection 9:271-274.

Gwynne, D. C. and Murray, R. B. 1985. Weed Biology and Control in Agriculture and Horticulture. Batsfort Academic and Educational. London.

Hadas, A., Bar-Yosef, B., Davidov, S., Sofer, M. 1983. Effect of pelleting, temperature and soil type on mineral nitrogen release from poultry and dairy manures. Soil Science Society of America Journal. 47:1129-1133.

Howard, R.J., Garland, J.A. and Seaman, W.L. (Eds.) 1994. Diseases and Pests of Vegetable Crops in Canada. The Canadian Phytopathological Society and the Entomological Society of Canada. Ottawa.

Hume, L., Martinez, J. and Best, K. 1983. The biology of Canadian Weeds, 60. *Polygonum convolvulus L.* Canadian Journal of Plant Science 63:959-971.

Iwata, I., Takayanagi, S. 1980. Studies on the damage to upland crops caused by weeds. 4. Effect of weeds on the growth and nitrogen aborption in corn. Weed Research, Japan 25: 53-257.

Jansson, R.K., Liebee, G.L., Sanchez, C.A. and Lecrone, S.H. 1991. Effects of nitrogen and foliar biomass on population parameters of cabbage insects. *Entomologia Experimentalis et Applicata* 61:7-16.

Jones, J.B. Jr. and Case, Vernon W. 1990. Sampling, handling and analyzing plant tissue samples. In Westerman, R.L. (Ed.) Soil Testing and Plant Analysis. Soil Science Society of America, Inc. Madison, WI.

Jones, J.B. Jr., Large, R.L., Pfeiderer, D.B. and Klosky, H.S. 1971. The proper way to take a plant sample for tissue analysis. Crops and Soil 23:15-18.

Klohn Leonoff, Ltd., W.R. Holm and Associates and G.G. Runka Land Sense, Ltd. 1992. Delta Agricultural Study.Agri-food Regional Development Subsidiary Agreement (ARDSA). Vancouver, B.C.

Koritsas, V.M. and Garsed, S.G. 1985. The effects of nitrogen and sulfur nutrition on the response of Brussels sprout plants to infestation by the aphid *Brevicoryne brassicae.* Annals of Applied Biology 106:1-15.

Kowalenko, C.G. 2000. Nitrogen pools and processes in agricultural systems of Coastal British Columbia - A review of published research. Canadian Journal of Plant Science 80:1-10.

Kowalenko, G. 1987. The dynamics of inorganic nitrogen in a Fraser Valley soil with and without spring or fall ammonium nitrate applications. Canadian Journal of Soil Science 67:367-382.

Kowalenko, C.G. and Hall, J.W. 1987. Effects of nitrogen applications on direct-seeded broccoli from a single harvest adjusted for maturity. Journal of the American Society of Horticultural Science 112:9-13.

Krzic, M. 1997. Tillage-planting systems and cover cropping for sweet corn production in the western Fraser Valley. Ph. D. Thesis. University of British Columbia. Department of Soil Science.

Lazarovits, G. 2001. Management of soil-borne plant pathogens with organic soil amendments: a disease control strategy salvaged from the past. Canadian Journal of Plant Pathology 23:1-7.

Lazarovits, G. and Conn, K. 1997. Assessment of the influence of manures for the control of soilborne pests including fungi, bacteria and nematodes. Canada-Ontario Agriculture Green Plan, COESA Resport No. RES/MAN-010/97. http://res2.agr.ca/initiatives/manurenet/ env_prog/gp/ gpres/report/rep16sum.html.

Lebaron, M.J. April 1974. A description: Developmental stages of the common bean plant. Current Information Series No. 228. University of Idaho.

Lorenz, O.A. and Maynard, D.N. 1980. Knott's Handbook for Vegetable Growers, 2nd Edition. John Wiley and Sons.

Lorenz, O.A. 1978. Nitrate Levels in Edible Plant Parts. in Nitrogen in the Environment, Volume 2. Soil-Plant-Nitrogen Relationships. D.R. Neilson and J.A. MacDonald (Eds.) Academic Press, New York. pp. 201-219.

Luttmerding, H.A. 1981. RAB Bulletin 18. Soils of the Vancouver-Langley Map Area. Report No. 15. British Columbia Soil Survey, Volume 6.

Marschner, H. 1995. Mineral Nutrition of Higher Plants. Academic Press. London; San Diego.

McHugh, J.J. Jr. and Foster, R.E. 1995. The influence of macronutrient fertilization on diamondback moth infestation on head cabbage. Journal of Vegetable Crop Production 1:81-95.

McKeague, J.A. 1978. Manual on Soil Sampling and Methods of Analysis, 2nd Ed. Canadian Society of Soil Science.

McLean, E.O. 1982. Soil pH and lime requirement. In A.L. Page, R.H. Miller, and D.R. Kennedy (Ed.) Methods of Soil Analysis. Part 2. 2nd Ed. Agronomy Monogr. 9. ASA-SSSA. Madison, WI. pp. 199-224.

Mills, H.A. and Jones, J.B. Jr. 1996. Plant Analysis Handbook II: a Practical Sampling, Preparation, Analysis and Interpretation Guide. MicroMacro Publishing, Inc. Athens, GA.

Mills, H.A. and Jones, J.B. Jr. 1979. Nutrient deficiencies and toxicities in plants: Nitrogen. Journal of Plant Nutrition 1:101-122.

Mohler, C.L. 2001. Weed life history: identifying vulnerabilities. In M. Leibman, C.L. Mohler and C.P. Staver (Eds.) Ecological Management of Agricultural Weeds. Cambridge University Press, Cambridge. pp. 40-98.

Nafuma, L.S. 1998. Short-term effects of graminaceous cover crops on autumn soil mineral nitrogen cycling in western lower Fraser Valley Soils. Ph.D. Thesis. University of British Columbia. Department of Soil Science.

Nelson, D.S. and Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In A.L. Page, R.H. Miller and D.R. Kennedy (Eds.) Methods of Soil Analysis. Part 2. 2nd ed., Agronomy Monograph 9. ASA-SSSA. Madison, WI. pp. 539-579.

Nelson, D.W. 1984. Effect of nitrogen excess on quality on food and fibre. in Nitrogen in Crop Production. R.D. Hauck. (Ed.) American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. pp. 643-662.

Neufeld, J.H. 1980. Soil Testing Methods and Interpretations. British Columbia Ministry of Agriculture Pulications 80-2.

Okumura, T., Takeuchi, S., Sugino, M. 1986. Competition between corn plants and weeds for uptake of nitrogen fertilizer. Memoirs of the Faculty of Agriculture of Kinki University 19:1-8.

Pang, X.P. and Letey, J. 2000. Organic farming: challenge of timing nitrogen availability to crop nitrogen requirements. Soil Science Society of America Journal 64:246-253.

Parkinson, J.A. and Allen, S.E. 1975. A wet oxidation method for the determination of nitrogen and mineral nutrients in biological material. Communications in Soil Science and Plant Analysis 6:1-11.

Pearson, A.J., Spiers, T.M., Cant, G. 1998. Crop uptake of nitrogen, phosphorus and potassium from soil amended with chicken manure and green waste compost. Proceedings of the Agronomy Society of New Zealand 28:31-34.

Pratt, P.F., Broadbent, F.E. and Martin, J.P. 1973. Using organic wastes as nitrogen fertilizers. California Agriculture 27:10-13.

Principe, L.L. 2001. Plant Species Abundance, Diversity and Soil Quality of Grassland Set-asides on the Fraser River Delta. M.Sc. Thesis. University of British Columbia. Department of Soil Science.

Qafoku, O.S., Cabrera, M.L., Windham, W.R., Hill, N.S. 2001. Rapid methods to determine potentially mineralizable nitrogen in broiler litter. Journal of Environmental Quality 30: 217-221.

Ritchie, S.W. and Hanway, J.J. February 1984. How a corn plant develops. Special Report No. 48. Iowa State University of Science and Technology Cooperative Extension Service. Ames, Iowa.

SAS Institute. SAS/STAT User's Guide, Fourth Edition. SAS Institute, Inc. Cary, N.C.

Schreier, H., Bestbier, R., Derksen G. and Brisbin, P. 2000. Issues, Trends and Concerns about Agricultural Nutrient Management in the Lower Fraser Valley. CD-ROM. http://www.ire.uB.C..ca/y2k/ire/html/cd-rom.htm

Serna, M.D. and Pomares, F. 1990. Comparison of biological and chemical methods to predict nitrogen mineralization in animal wastes. Biology and Fertility of Soils 12:89-94.

Straw, R.A., Mullins, C.A., Coffey, D.L. and Lessman, G.M. 1993. Nitrogen fertilization of sweet corn varieties. Tennessee Farm and Home Science 166:20-24.

Talpaz, H., Fine, P and Bar-Josef, B. 1981. On the estimation of N-mineralization parameters from incubation experiments. Soil Science Society of America Journal 45:993-995.

Temple, W.D., Bomke, A.A., Principe, L. and Park, A. 2000. Farmland Stewardship in Delta, Phase 9: 1999-2000 Interim Annual Report.

Thomas, G.W. 1982. Exchangeable cations. In A.L. Page, R.H. Miller, and D.R. Kennedy (ed.) Methods of Soil Analysis. Part 2. 2nd Ed. Agronomy Monogr. 9. ASA-SSSA. Madison, WI. pp. 159-165.

Turkington, R., Kenkel, N.C., Franko, G.D. 1980. The biology of Canadian Weeds, 42. *Stellaria media* (L.)Vill. Canadian Journal of Plant Science 60:981-992.

United States Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Department of Agriculture Handbook. no. 60.

Vizcarra, A.T., Lo, V.L. and Lavkulich, L.M. 1997. Nitrogen balance in the lower Fraser river basin of British Columbia. Environmental Management 21:269-282.

Vyn, T.J., Janovicek, K.J., Miller, M.H. and Beauchamp, E.G. 1999. Soil nitrate accumulation and corn response to preceding small-grain fertilization and cover crops. Agronomy Journal 91:17-24.

Walse, C., Berg, B., Sverdup, H. 1998. Review and synthesis of experimental data on organic matter decomposition with respect to the effect of temperature, moisture and acidity. Environmental Reviews 6:25-40.

Weaver, S.E. and McWilliams, E.L. 1980. The biology of Canadian Weeds, 44. *Amaranthus retroflexus* L., *A.powelii* S.Wats. and *A. hybridus* L. Canadian Journal of Plant Science 60:1215-1234.

Weinberg, N.H. 1987. Improving nitrogen fertilizer recommendations for arable crops in the lower Fraser Valley. M. Sc. Thesis. University of British Columbia.

Zebarth, B.J., Bowen, P.A. and Toivonen, P.M.A. 1995. Influence of nitrogen fertilization on broccoli yield, nitrogen accumulation and apparent fertilizer-nitrogen recovery. Canadian Journal of Plant Science 75:717-725.

Zebarth, B.J., Hii, B., Liebscher, H., Chipperfield, K., Paul, J.W., Grove, G. and Szeto, S.Y. 1998. Agricultural land use practices and nitrate contamination in the Abbotsford Aquifer, British Columbia, Canada. Agriculture, Ecosystems and Environment 69: 99-120.

Zebarth, B.J., Paul, J.W. and Van Kleek, R. 1999. The effect of nitrogen management in agricultural production on water and air quality: evaluation on a regional scale. Agriculture, Ecosystems and Environment 72:35-52.

Zimdahl, 1980. Weed-Crop Competition, A Review. International Plant Protection Centre, Oregon State University, Corvallis.

Appendix A : Statistical Tables

Table A.1. t-test for the nitrogen application of the two manure sources on broccoli field

Source	t/ha(wet)	Mean kgN/ha	SD	SEM	DF	$t_{0.05(v)}$ †	t_{crit} ‡
1	8.42	273.2	22	15.56	1*	4.12	1.886
2	18.43	326.97	22.6	13.06	2		

† Calculated as (326.97-273.2)/13.06

‡ one-tailed critical t-value, p=0.05

* one of the rate measurement trials was an outlier and was omitted

Table A.2. t-tests comparing mean ammonium levels to zero

Data Set	**Mean NH_4^+(mg/kg soil)**	**SD**	**SEM**	**DF**	**$t_{0.05(v)}$** †	**t_{crit}** ‡
N-budget - corn*	0.05	0.11	0.03	19	2.08	1.729
N-budget - beans	0.58	1.59	0.36	19	1.63	1.729[1]
N-budget - broccoli	-1.17	2.61	0.58	19	-2.00	1.729
Incubation#1 - 31d	-0.68	0.38	0.060	39	-11.43	1.645
Incubation#1 - 74d	0.39	0.79	0.12	39	3.12	1.645
Incubation#2 - 30d	0.40	0.69	0.13	27	3.07	1.703
Incubation#2 - 61d	0.63	0.73	0.14	27	4.54	1.703
Autumn Soil - corn	21.23	27.77	6.21	19	3.42	1.729
Autumn Soil - beans	7.25	6.96	1.56	19	4.66	1.729
Autumn Soil - broccoli	1.12	1.89	0.42	19	2.65	1.729

*blank values were negative, and thus were not subtracted from raw NH_4^+ readings

† t value calculated as (Mean NH_4^+ - N)/SEM

‡ two-tailed critical t-value, at p=0.05

[1]significant at p<0.05

Table A.3. A.N.O.V.A. Table for clubroot, pest and beneficial insect assessments in broccoli Trial with five fertilizer treatments, sampled August (pests and beneficials) and October (clubroot) 2001

Category	Source of Variation	DF	SS	F-Value[1]	P-Value
Beneficials	Block	3	18.4	0.51	0.6809
	Treatment	4	14.6	0.30	0.8693
	Error 1	12	143.4	3.38 (E2)	0.0018
	Error 2	40	141.3	-	-
Aphids	Block	3	2730.0	2.91	0.0781
	Treatment	4	594.6	0.48	0.7532
	Error 1	12	3751.2	0.73 (E2)	0.7165
	Error 2	40	17190.0	-	-
Lepidopterans	Block	3	16.6	0.95	0.4464
	Treatment	4	56.7	2.44	0.1040
	Error 1	12	69.7	0.61 (E2)	0.8185
	Error 2	40	379.3	-	-
Thrips	Block	3	16.7	2.01	0.1661
	Treatment	4	3.3	0.29	0.8759
	Error 1	12	33.3	2.16 (E2)	0.0342
	Error 2	40	51.3	-	-
Clubroot	Block	4	5326.1	2.66	0.0959
	Treatment	3	15498.7	5.80	0.0078
	Error 1	12	8019.0	1.00	0.4509
	Error 2	180	120297.3	-	-

Error 1 is Block x Treatment
[1]Tested over Error 1 unless otherwise indicated

Table A.4. A.N.O.V.A. Table for disease assessments of bean trial with five fertilizer treatments, sampled July and August, 2001.

Date Sampled	Category	Source of Variation	DF	SS[1]	F-Value	P-Value
July 26	Rhizoctonia	Block	3	2645.0	3.93	0.0362
		Treatment	4	342.1	0.38	0.8176
		Error 1	12	2689.0	2.23 (E2)	0.0113
		Error 2	238	21977.4	-	-
August 12	Rhizoctonia	Block	3	1230.5	2.6	0.1004
		Treatment	4	955.8	1.52	0.2593
		Error 1	12	1892.6	3.10 (E2)	0.0012
		Error 2	80	4075.0	-	-
	Grey Mold (Leaves)	Block	3	15.5	3.06	0.0693
		Treatment	4	11.1	1.65	0.2250
		Error 1	12	20.2	1.74	0.0741
		Error 2	80	77.6	-	-
	Grey Mold (Stems)	Block	3	8.7	4.43	0.0257
		Treatment	4	18.3	6.96	0.0039
		Error 1	12	7.9	0.68 (E2)	0.7701
		Error 2	80	78.0	-	-

Error 1 is Block x Treatment

[1]Tested over Error 1 unless otherwise indicated

Table A.5. A.N.O.V.A. Table for weed frequency survey of corn trial with five fertilizer treatments, sampled August, 2001.

Weed	Source of Variation	DF	SS	F-Value	P-Value
Chenopodium album	Block	3	5.2	0.57	0.6435
	Treatment	4	7.7	0.64	0.6464
	Error	12	36.3	-	-
Polygonum convolvulus	Block	3	48.4	1.68	0.2236
	Treatment	4	26.5	0.69	0.6123
	Error	12	115.1	-	-
Stellaria media	Block	3	28.5	6.00	0.0097
	Treatment	4	9.2	1.60	0.2364
	Error	12	17.2	-	-
Polygonum persicaria	Block	3	1.0	0.05	0.9859
	Treatment	4	14.5	0.51	0.7305
	Error	12	85.5	-	-
Amaranthus retroflexus	Block	3	1.0	0.29	0.8348
	Treatment	4	4.0	0.86	0.5165
	Error	12	14.0	-	-
Senecio sp.	Block	3	1.0	1.15	0.3683
	Treatment	4	1.5	1.36	0.3036
	Error	12	3.3	-	-
Capsella bursa-pastoris	Block	3	0.2	1.00	0.4262
	Treatment	4	0.2	1.00	0.4449
	Error	12	0.6	-	-

Table A.6. A.N.O.V.A. Table for weed abundance survey of corn trial with five fertilizer treatments, sampled August, 2001.

Weed	Source of Variation	DF	SS	F-Value	P-Value
Chenopodium album	Block	3	469.8	0.69	0.5753
	Treatment	4	337.6	0.37	0.8242
	Error	12	2722.7	-	-
Polygonum convolvulus	Block	3	403.0	0.39	0.7641
	Treatment	4	628.4	0.45	0.7685
	Error	12	4160.2	-	-
Stellaria media	Block	3	198.5	0.93	0.4545
	Treatment	4	277.7	0.98	0.4547
	Error	12	850.7	-	-
Polygonum persicaria	Block	3	1918.3	2.74	0.0896
	Treatment	4	868.7	0.93	0.4786
	Error	12	2801.2	-	-
Amaranthus retroflexus	Block	3	198.5	0.90	0.4718
	Treatment	4	270.8	0.92	0.4860
	Error	12	887.2	-	-
Senecio sp.	Block	3	205.8	0.96	0.4446
	Treatment	4	296.7	1.03	0.4292
	Error	12	860.5	-	-
Capsella bursa-pastoris	Block	3	216.6	1.00	0.4262
	Treatment	4	288.8	1.00	0.4449
	Error	12	866.4	-	-

Table A.7. A.N.O.V.A. Table for for weed frequency survey of bean trial with five fertilizer treatments, sampled August, 2001.

Weed	Source of Variation	DF	SS	F-Value	P-Value
Chenopodium. album	Block	3	30.2	2.51	0.1085
	Treatment	4	18.3	1.14	0.3834
	Error	12	48.1	-	-
Polygonum persicaria	Block	3	1.80	0.12	0.9462
	Treatment	4	6.8	0.35	0.8379
	Error	12	58.0	-	-
Polygonum convolvulus	Block	3	12.4	1.19	0.3541
	Treatment	4	10.0	0.72	0.5938
	Error	12	41.6	-	-
Senecio sylvaticus	Block	3	0.2	1.00	0.4262
	Treatment	4	0.2	1.00	0.4449
	Error	12	0.6	-	-

Table A.8. A.N.O.V.A. Table for for weed abundance survey of bean trial with five fertilizer treatments, sampled August, 2001.

Weed	Source of Variation	DF	SS	F-Value	P-Value
Chenopodium. album	Block	3	412.1	2.10	0.1538
	Treatment	4	292.1	1.12	0.3937
	Error	12	785.1	-	-
Polygonum persicaria	Block	3	75.5	0.19	0.8992
	Treatment	4	589.2	1.13	0.3888
	Error	12	1566.5	-	-
Polygonum convolvulus	Block	3	1.3	1.90	0.1827
	Treatment	4	0.2	0.20	0.9335
	Error	12	2.6	-	-
Senecio sylvaticus	Block	3	0.038	1.00	0.4262
	Treatment	4	0.05	1.00	0.4449
	Error	12	0.15	-	-

Table A.9. A.N.O.V.A. Table for diagnostic plant tissue N levels, sampled July - September 2001.

Crop	Source of Variation	DF	SS[1]	F-Value	P-Value
Corn	Block	3	0.019	0.24	0.8650
	Treatment	4	0.818	7.68	0.0026
	Error	12	0.320	-	-
Beans	Block	3	0.177	1.82	0.1978
	Treatment	4	1.274	9.83	0.0009
	Error	12	0.389	-	-
Broccoli	Block	3	n/a	n/a	n/a
	Treatment	4	n/a	n/a	n/a
	Error	12	n.a	-	-

[1] Calculated on the basis of % N content

Table A.10. A.N.O.V.A. Table for harvest data in corn, bean and broccoli trials with five fertilizer treatments, sampled August-September 2001

Crop	Category	Source of Variation	DF	SS[1]	F-Value	P-Value
Corn	Marketable Yield	Block	3	8.05	5.16	0.0161
		Treatment	4	6.01	2.89	0.0691
		Error	12	6.25	-	-
	Vegetative Yield[2]	Block	3	3.69	2.33	0.1258
		Treatment	4	6.58	1.04	0.4273
		Error	12	19.00	-	-
	Stalk #	Block	3	7.00	0.44	0.7256
		Treatment	4	5.80	0.28	0.8877
		Error	12	63.00	-	-
	Cob #	Block	3	63.60	6.71	0.0066
		Treatment	4	31.30	2.48	0.1002
		Error	12	132.80	-	-
	Tiller #	Block	3	60.550	2.48	0.1111
		Treatment	4	120.70	3.71	0.0346
		Error	12	278.95	-	-
	Dry Cob Wt	Block	3	1316.80	1.12	0.3786
		Treatment	4	5130.80	3028	0.0491
		Error	12	11138.80	-	-
Beans	Marketable Yield	Block	3	0.164	1.77	0.2507
		Treatment	4	0.633	5.14	0.0120
		Error	12	0.370	-	-
	Vegetative Yield[2]	Block	3	0.032	0.52	0.6767
		Treatment	4	0.417	5.12	0.0121
		Error	12	0.244	-	-
Broccoli	Marketable Yield	Block	3	688846.6	1.59	0.2443
		Treatment	4	571902.5	0.99	0.4509
		Error	12	1737620.7	-	-
	Vegetative Yield[2]	Block	3	0.512	2.63	0.0982
		Treatment	4	0.839	3.23	0.0514
		Error	12	0.780	-	-

[1]SS was calculated on raw data in kg for corn and beans and in g for broccoli
[2] Vegetative biomass was analyzed on a t/ha dry weight basis

Table A.11. A.N.O.V.A. Table for NO_3^--N levels in soil (0-30cm depth) in corn, bean and broccoli fields, sampled November, 2001.

Field	Source of Variation	DF	SS[1]	F-Value	P-Value
Corn	Block	3	15.1	0.28	0.8378
	Treatment	4	1788.3	24.93	0.0001
	Error	12	2018.7	-	-
Beans	Block	3	356.9	0.45	0.7227
	Treatment	4	429.4	0.40	0.8016
	Error	12	3967.8	-	-
Broccoli	Block	3	75.3	0.39	0.7605
	Treatment	4	7521.7	29.43	0.0001
	Error	12	8363.7	-	-

[1] calculated on the basis of mg NO_3^--N/kg soil

Table A.12. A.N.O.V.A. Table for N uptake of corn, bean and broccoli crops and barley cover crop, sampled August (corn and beans), September (broccoli), and November (barley) 2001.

Crop	Crop Part	Source of Variation	DF	SS[1]	F-Value	P-Value
Corn	Vegetative	Block	3	3102.7	2.28	0.1312
		Treatment	4	2592.8	1.43	0.2831
		Error	12	5437.9	-	-
	Cobs	Block	3	1258.6	7.02	0.0056
		Treatment	4	846.3	3.54	0.0395
		Error	12	716.8	-	-
Beans	Vegetative	Block	3	49.2	0.89	0.4749
		Treatment	4	250.0	3039	0.0450
		Error	12	221.6	-	-
	Fruit	Block	3	626.6	0.55	0.6597
		Treatment	4	7843.0	5.13	0.0121
		Error	12	4583.6	-	-
Broccoli	Vegetative	Block	3	966.1	2.19	0.1421
		Treatment	4	2651.8	4.51	0.0187
		Error	12	5382.1	-	-
	Florets	Block	3	401.1	2.01	0.1666
		Treatment	4	113.9	0.43	0.7861
		Error	12	1314.0	-	-
Barley	Whole plant	Block	3	2664.1	1.43	0.2821
		Treatment	4	2091.4	0.84	0.5242
		Error	12	7442.8	-	-

[1] Calculated on a kg N/ha basis

Table A.13. A.N.O.V.A. Table for soil mineral N + crop N at harvest as a percentage of total fertilizer N applied (kg N/ha) in three field experiments.

Experiment	Source of Variation	DF	SS	F-Value	P-Value
Corn	Block	3	3011.3	1.49	0.2672
	Treatment	4	931.7	0.35	0.8421
	Error	12	8087.2	-	-
Beans	Block	3	1253.2	0.74	0.5478
	Treatment	4	8867.7	3.93	0.0289
	Error	12	6764.6	-	-
Broccoli	Block	3	3154.0	4.55	0.0238
	Treatment	4	9822.5	10.63	0.0006
	Error	12	2772.5	-	-

Table A.14. Soil mineral N+crop N at harvest as a percentage of total fertilizer N applied (kg N/ha) in three field experiments.

Treatment	Corn	Beans	Broccoli
Compost	12.18a	-49.95b	15.9b
Mix	1.65a	-5.25a	56.4a
Manure x 1	10.43a	-9.63ab	36.9ab
Manure x 2	18.33a	18.53a	55.7a

within-crop results with the same letter are not significantly different according to Duncan's multiple range test at $p<0.05$

Table A.15. Calculation of the coefficient of variation for the single application rate of manure in three field experiments

Experiment	Mass Measured (kg)	Tarp Area (m^2)	t/ha
Corn/beans	13.7	10.4	13.2
Corn/beans	13.3	10.4	12.8
Corn/beans	16.2	10.4	15.6
Broccoli	3.7	4.55	8.1
Broccoli	3.3	4.55	7.3
Broccoli	2.3	4.55	5.1
Broccoli	8.1	4.55	17.8
Broccoli	9.1	4.55	20
Broccoli	8.1	4.55	17.8
		Mean	13. 1
		SD	5.3
		CV	**0.402895**

Table A.16. A.N.O.V.A. Table for N concentration of plant parts for corn, beans and broccoli, sampled August (Corn, Beans) and September (Broccoli), 2001.

Crop	Part	Source of Variation	DF	SS[1]	P-Value	F-Value
Corn	Vegetative	Block	3	0.103	5.79	0.0110
		Treatment	4	0.022	1.25	0.3424
		Error	12	0.214	-	-
	Cobs	Block	3	0.319	11.43	0.0008
		Treatment	4	0.175	6.27	0.0058
		Error	12	0.335	-	-
Beans	Vegetative	Block	3	0.723	5.31	0.0147
		Treatment	4	0.719	3.96	0.0284
		Error	12	0.545	-	-
	Fruit	Block	3	1.196	2.02	0.1643
		Treatment	4	2.277	2.89	0.0689
		Error	12	2.364	-	-
Broccoli	Vegetative	Block	3	1.592	3.30	0.0575
		Treatment	4	1.106	1.72	0.2098
		Error	12	1.928	-	-
	Florets	Block	3	0.756	1.5	0.2643
		Treatment	4	1.603	2.39	0.1092
		Error	12	2.014	-	-
	Florets - NO_3^--N*	Block	3	18845500	1.94	0.1769
		Treatment	4	10827000	0.84	0.5278
		Error	12	28837000	-	-

[1] calculated on the basis of %N on a dry weight basis, except *, calculated on a mg/kg dry weight basis

Table A.17. Mean nitrogen concentration, in % dry matter, of vegetative and reproductive parts of three crops measured at harvest

Treatment	Corn		Beans		Broccoli	
	Vegetative	Cobs	Vegetative	Fruit	Vegetative	Florets
Control	1.71a	1.33c	2.37b	3.23ab	3.37a	5.73ab
Compost	1.82a	1.28c	2.74a	3.11b	3.47a	5.45b
Mix	1.82a	1.49bc	2.81a	3.49ab	3.81a	5.83ab
Manure x 1	1.83a	1.79a	2.87a	2.89b	3.89a	6.29a
Manure x 2	1.92a	1.62ab	2.88a	3.87a	3.96a	6.02ab

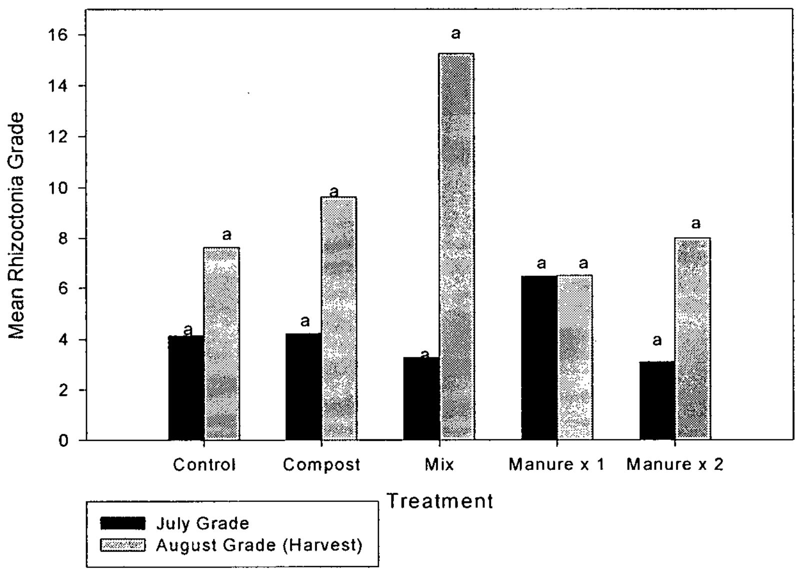

Figure A.1. Grades of rhizoctonia root-rot in July and August on bean roots.
within-sampling results with the same letter are not significantly different according to Duncan's multiple range test at $p<0.05$.

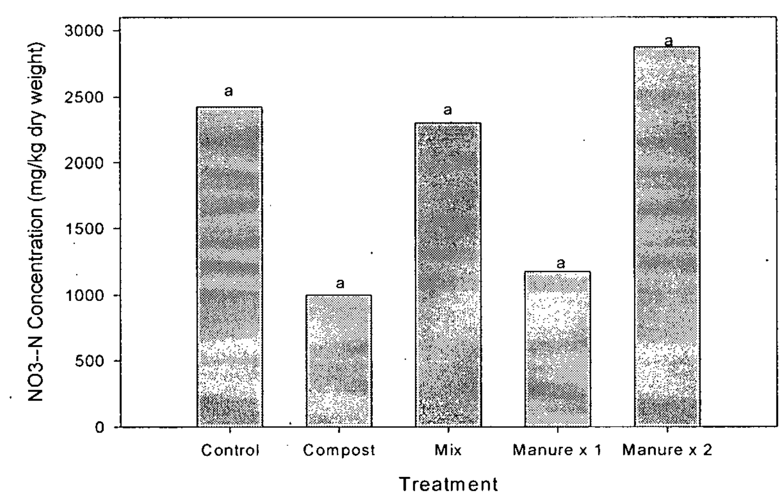

Figure A.2. Concentration of NO_3^--N in broccoli florets.
results with the same letter are not significantly different according to Duncan's multiple range test at $p<0.05$.

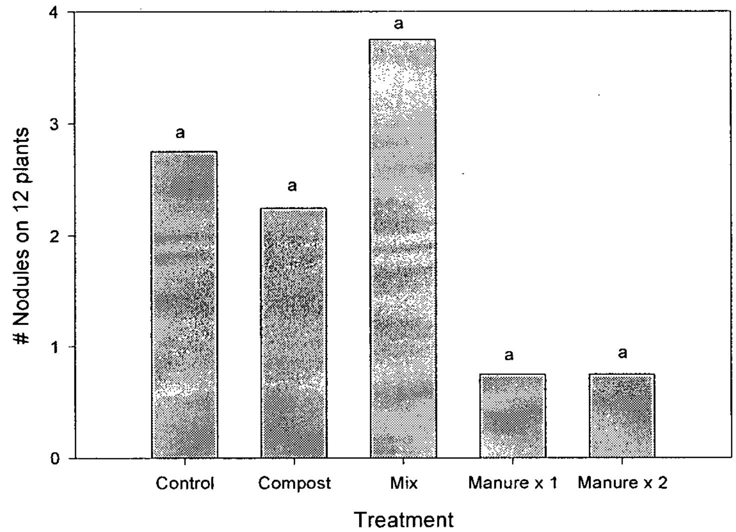

Figure A.3. Nodulation on beans as a function of fertilizer treatments.
results with the same letter are not significantly different according to Duncan's multiple range test at $p<0.05$.

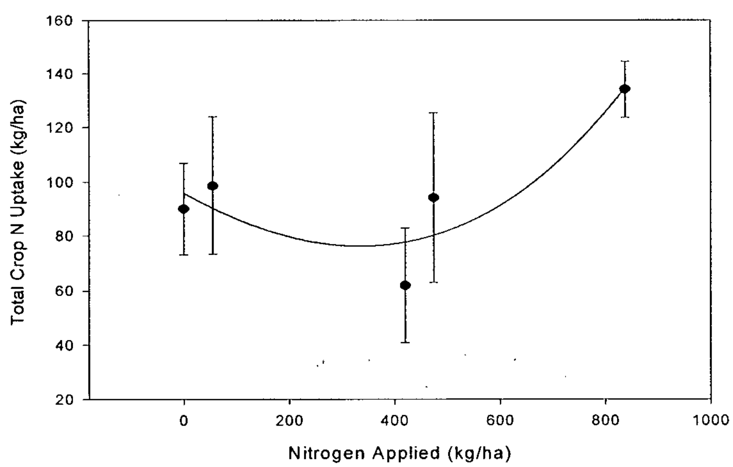

Figure A.4. Bean N uptake as a function of nitrogen applied by organic fertilizers.
error bars show +/- one standard deviation about the mean

Appendix B : Sample Calculations

1. Conversion of subjective grades to the mid-point of the range they represent: (clubroot scheme as an example)

Table B.1. Conversion of raw clubroot scores into the midpoint of the range of severity they represent.

Grade	Range of Rooting Volume Affected (%)	Midpoint*
0	0	0
1	1-5	2.5
2	6-25	15.5
3	26-50	38
4	51-100	75.5

*midpoint numbers were used in statistical analyses.

2. Calculation of mg NO_3^- /kg fresh broccoli florets, and error due to instrumentation:

TKN (excluding NO_3^--N) - TKN(including NO_3^--N) = 5.88-6.48 = 0.6 % NO_3^--N /dry floret weight

$$\frac{0.6\text{g } NO_3^-\text{-N}}{100 \text{ g dry floret}} \times \frac{1000\text{mg } NO_3^-\text{-N}}{\text{kg } NO_3^-\text{-N}} \times \frac{1000 \text{ g floret}}{\text{I kg floret}} = \frac{6000 \text{ mg } NO_3^-\text{-N}}{\text{kg dry floret}}$$

$$\frac{6000 \text{ mg } NO_3^-\text{-N}}{\text{kg dry floret}} \times (1-0.92623\text{[1]}) = \frac{442.6 \text{ mg } NO_3^-\text{-N}}{\text{kg fresh floret}}$$

$$\frac{442.6 \text{ mg } NO_3^-\text{-N}}{\text{kg fresh floret}} \times \frac{62.01 \text{ mg } NO_3^-}{14.01 \text{ mg } NO_3^-\text{-N}} = \frac{1960 \text{ mg } NO_3^-}{\text{kg fresh floret}}$$

To calculate maximum NO_3^- concentration that falls within possible instrumentation error, subtract 0.08 from the TKN value, and add 0.08 to the (TKN + NO3--N) value. For the minimum, do the opposite, as shown below:

Table B.2. Calculation of nitrogen readings within instrumentation error that result in the widest range of NO_3^- concentrations.

% N	Value Given	Maximum	Mimimum
TKN without NO_3^-	5.88	5.80	5.96
TKN with NO_3^-	6.48	6.56	6.40

These new pairs of numbers are used to calculate nitrate concentration as shown above.

[1] moisture content of that particular sample of broccoli florets

3. Sample calculation of the application rate simulated by the incubation experiments:

Desired Rate for Simulation: 7.5 t/ha dry manure
Dry Soil per Incubation Pot: 314 g
Moisture Content of Specific Manure Source: 0.3

$$\frac{7.5 \text{ t manure}}{\text{ha soil}} \times \frac{\text{I ha}}{2000\,000\,000 \text{ g soil}^{2}} \times 314\text{g soil} \times \frac{1000\,000 \text{ g manure}}{\text{I t manure}} = 1.18 \text{ g}$$

1.18 g dry manure applied to each pot. The specific moisture content of each manure source was used to calculcate the fresh application as follows:

1.18 g dry manure /(1-0.3) = 1.69 g fresh manure in the pot

4. Conversion of $mgNO_3^-$/L KCl solution to mg NO_3^-/kg soil:

$$\frac{(mgNO_3^- \text{-N - mean } mgNO_3^- \text{-N of control pots})}{\text{L KCl}} \times \frac{0.1 \text{ L KCl}}{\text{g dry soil in sample}} \times \frac{1000 \text{ g dry soil}}{1 \text{ kg dry soil}}$$

$$= \frac{mgNO_3^- \text{-N}}{\text{kg dry soil}} \times \frac{2\,400\,000 \text{ kg dry soil}^{3}}{\text{ha}} \times \frac{1 \text{ kg N}}{1000 \text{ mg N}}$$

$$= \frac{\text{kg } NO_3^- \text{-N}}{\text{ha}}$$

[2] based on an assumed forrow slice of 20 cm and soil bulk density of 1t/m^3
[3] based on an assumed forrow slice of 20 cm and soil bulk density of 1.2 t/m^3

Appendix C : Soil Moisture Retention Curve for Delta

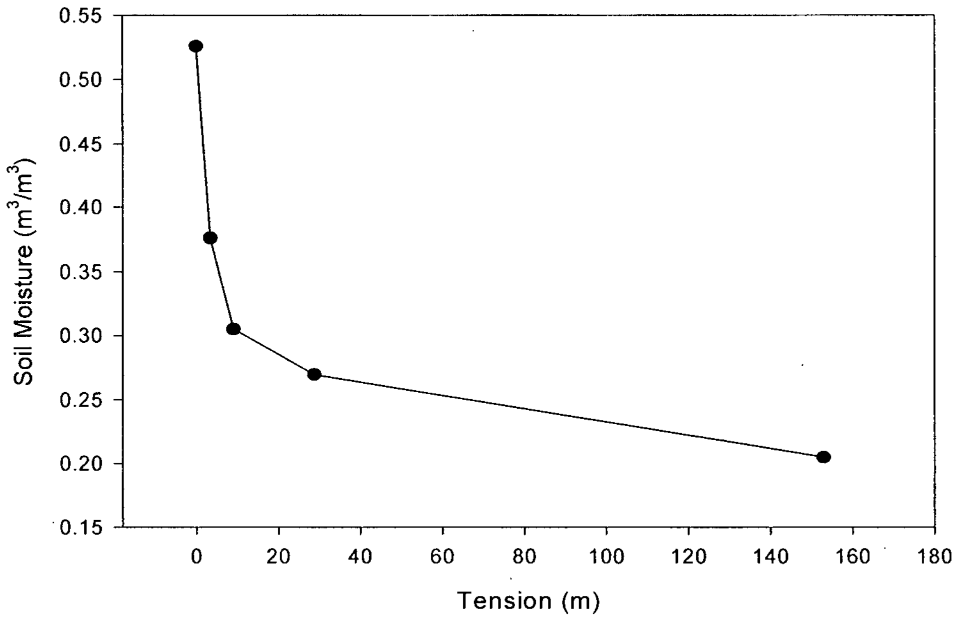

Figure C.1. Moisture retention curve for Westham Island soils, Delta, B.C.
(from Temple, W.D. unpublished data)
*field capacity is at y=0.33