# FOOD AND YARD WASTE COMPOST AS A NUTRIENT SOURCE FOR CORN PRODUCTION

by

Angela E. Garnett

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Co-Supervisors: ________________________________

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Signature of Author

# Thesis Dedication

I would like to dedicate my Masters of Science Graduate thesis to my Dad, Brian Garnett, who would be incredibly proud of me today. He always showed his daughters that the things worth having in life take hard work and dedication.

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# Abstract

Utilizing food and yard waste (FYW) compost for plant production requires determination of application rates that support crop production, improve soil properties and avoid excessive nutrient build-up. An 88 day incubation experiment showed 12 t ha$^{-1}$ FYW compost to contribute 3.6 kg M3P ha$^{-1}$ and 0.3 kg mineral N ha$^{-1}$, 24 t ha$^{-1}$ supplied 15.1 kg M3P ha$^{-1}$ and 0.7 kg N ha$^{-1}$ and 36 t ha$^{-1}$ gave 39.5 kg M3P ha$^{-1}$ and 1.2 kg N ha$^{-1}$ to Pugwash series coarse, loamy soil. A field study showed FYW compost yielded higher P concentrations in grain and stover but lower grain yields than fertilizer. In the residual year, compost treatment yields didn’t decrease and concentrations and amounts of P and N increased. This FYW compost applied to corn at 24 t ha$^{-1}$ with an N fertilizer can yield similarly to fertilizers only, removing greater amounts of P in grain and stover.

## List of Abbreviations Used

| | |
|---|---|
| Al | aluminum |
| ATP | adenosine triphosphate |
| BMPs | beneficial management practices |
| C | carbon |
| Ca | calcium |
| CEC | cation exchange capacity |
| C:N | carbon to nitrogen ratio |
| CHU | corn heat unit |
| DM | dry matter |
| E1 | experiment 1 |
| E2 | experiment 2 |
| Fe | iron |
| FYW | food and yard waste |
| ha | hectare |
| $H_2PO_4^-$ | di-hydrogen phosphate |
| $HPO_4^{-2}$ | hydrogen phosphate |
| ICAP | inductively coupled argon plasma spectrophotometer |
| kg | kilogram |
| Mn | manganese |
| M3P | Mehlich III extractable phosphorus |
| mg | milligram |
| MSW | municipal solid waste |

| | |
|---|---|
| N | nitrogen |
| $N_2$ | nitrogen gas |
| N/A | not available |
| $NH_3$ | ammonia |
| $NH_4^+$ | ammonium |
| $NH_4^+$-N | ammonium-nitrogen |
| NMP | nutrient management planning |
| NO | nitric oxide |
| $N_2O$ | nitrous oxide |
| $NO_2^-$ | nitrite |
| $NO_3^-$ | nitrate |
| $NO_3^-$N | nitrate-nitrogen |
| NS | Nova Scotia |
| NSDA | Nova Scotia Department of Agriculture |
| $O_2$ | oxygen |
| OM | organic matter |
| P | phosphorus |
| SEM | standard error of means |
| STP | soil test phosphorus |
| TP | total phosphorus |
| WFPS | water filled pore space |
| % | percent |

# Acknowledgements

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# Chapter 1.0 Introduction

## 1.1 Research Introduction

Social and environmental pressures to divert biodegradable wastes from entering landfills, coupled with improvements in composting technology, have led to an increase in the production of compost with value as a soil amendment and source of plant nutrients. In Nova Scotia (NS), sixteen organic composting facilities have been established (Province of Nova Scotia, 2008) with over 90,000 tonnes of waste organics being composted annually (Statistics Canada, 2008b). This biodegradable portion of municipal solid waste (MSW), is largely made up of kitchen and yard waste although other wastes such as sewage sludge are included as well, depending upon the individual composting facility. Municipal solid waste compost is high in organic matter (OM) content, has a low bulk density (Hargreaves *et al.,* 2008), and research has shown that it has the ability to improve soil properties (Mkhabela and Warman, 2005; Rodd *et al*., 2008) and the growth and yield of vegetables (Ozores-Hampton *et al.,* 1994; Warman *et al.,* 2009), with evidence of positive residual effects (Rodd *et al.,* 2000). However, results have shown that MSW compost's physical and chemical composition and its overall ability to supply nutrients tend to vary between facilities. This variability is often due to an inconsistency in the mixtures of raw materials; which tend to fluctuate by facility, by season and from year to year (Hargreaves *et al.,* 2008). Due to the wide variety of MSW raw material combinations studied and inconsistent results it is necessary to conduct research specific to food and yard waste (FYW) compost and its impacts on various agricultural crops.

Several of NS's organic composting facilities process only FYWs that are collected from residential and commercial curb side green bins, commonly distributed throughout most municipalities. The Northridge Farm composting facility, located in Kings County, produces in excess of 6,000 kg $yr^{-1}$ of finished FYW compost with their product being utilized in the local landscape, horticultural and agricultural industries. This facility, situated in the middle of NS's largest agricultural producing county, advocates research as a method of promoting MSW composts value as a soil amendment and source of nutrients for local agricultural production (Horsnell, 2010).

The NS Department of Agriculture (NSDA) promotes nutrient management planning (NMP) and partially funds associated costs with their Farm Investment Fund Program (NSDA, 2008). Nutrient management planning aims to minimize excessive nutrient application to crops (Burton *et al*., 2003) to avoid their loss from agricultural soils through leaching and surface runoff, which risks pollution of nearby surface water bodies (Sharpley, 1995). Thereby, a comprehensive understanding of the supply of plant available macro-nutrients, such as phosphorous (P) and nitrogen (N), is crucial when applying composts to meet crop requirements and improve soil properties. Plant available nutrients derived from an organic amendment, such as compost, have the potential to increase gradually through the mineralization process thereby, replenishing the pool of available N and P in the soil solution (Stewart and Tiessen, 1987). However, concentrations of nutrients and the subsequent mineralization rates tend to vary from compost to compost, contributing to unpredictable nutrient supply and consequently producer scepticism (Hargreaves *et al.*, 2008). The potential for FYW compost to supply plant available nutrients is evident (Sullivan *et al.,* 2002), although timing of compost applications to ensure synchrony with nutrient demanding crop growth stages is difficult due to the variability in nutrient mineralization rates. Therefore, it is necessary to conduct site specific research to examine both the agronomic benefits and environmental consequences of the application of FYW compost to agricultural soils to optimize its use in crop production (Mamo *et al.,* 1998).

In chapter 2 there is a brief introduction to both MSW and FYW compost, contrasting the two and their use in agricultural soils to support crop growth and as a soil amendment. The various forms of P and N in soils, their availability to plants for uptake, the specific roles of N and P in corn growth, and the importance of NMP to minimize excessive nutrient application are also reviewed.

Subsequent chapters present results from one laboratory experiment and two growing seasons of field research. Chapter 3 summarizes a laboratory incubation of FYW compost that compares various FYW compost application rates and their overall N and P content to quantify their respective rate of and net P and N mineralization. Chapter 4 introduces and Chapter 5 summarizes, two years of field research that identifies the potential of FYW compost to improve soil's physical and chemical properties while meeting nutrient requirements of grain corn to maintain yields over two consecutive growing seasons. Chapter 6 is a collaborative summary of findings from both the *in-situ* and laboratory experiments with recommendations for future use of this FYW compost.

## 1.2 Overview of Experiments

This project included two experiments (E1 and E2) which were intended to evaluate the benefits of a single application of FYW compost for grain corn production in

NS. Determining the nutrient release and benefits to soil properties will enable interested producers to incorporate this alternative nutrient source and soil amendment into their NMPs.

**Experiment 1:** This experiment was conducted in a controlled environment (i.e. temperature and moisture) and consisted of incubating FYW compost over an 88 d period, following the application of different rates of FYW compost to soil. This experiment attempted to identify: (i) the initial availability of N and P at the time of application, (ii) the overall rate of nutrient release based on application rate, and (iii) the time of maximum release for more efficient compost application timing. This experiment will inform future recommendations for compost application to grain corn crops that minimize excessive nutrient applications from an organic source thereby reducing the risk to the environment. The specific objective of E1 was to quantify the initial availability, the subsequent release rate and the change in concentrations of mineral N (nitrate-N + ammonium-N) and Mehlich III extractable phosphorus (M3P) from mixtures of soil and FYW compost in a controlled environment over 88 d.

**Experiment 2:** Consisted of an assessment of the initial (first year) response and residual (second year) effect of a single application of FYW compost supplemented with inorganic fertilizer on corn yield, nutrient utilization, and soil properties. The specific objectives of E2 were to:

(i) quantify N and P removal in corn grain and stover following a single application of three FYW compost rates in comparison to an inorganic fertilizer source,

(ii) quantify corn grain yield following a single application of three FYW compost rates in comparison to an inorganic fertilizer source, and

(iii) quantify changes in soil properties (i.e. pH, plant available P (M3P), cation exchange capacity (CEC) and OM) over two growing seasons following a single application of FYW compost.

# Chapter 2.0 Literature Review

## 2.1 Food and Yard Waste Compost

The organic, biodegradable portion of municipal solid wastes (MSW), are diverted from landfills and composted to reduce volume, kill pathogens, decrease weed seed populations and destroy malodorous compounds (Hargreaves *et al.,* 2008). This method of diverting organic waste materials from landfills results in a relatively low-cost product that produces a product that is suitable for agricultural purposes, thereby decreasing the requirement for commercial fertilizers (Hargreaves *et al.,* 2008). Composting transforms organic by-products into drier, more uniform and biologically stable products that can act as slow-release sources of plant-available nutrients (Sullivan *et al.*, 2002). Depending upon the handling facility and area of collection, in Nova Scotia (NS), MSW compost may consist of various combinations of household and/or commercial wastes including but not limited to: food, kitchen and yard waste, municipal sewage sludge, sawdust, paper products, fish processing waste, and biosolids (Province of Nova Scotia, 2008). The present study will evaluate one type of MSW compost that is comprised solely of residential and commercial food and yard waste (FYW), referring to it as such to avoid implying additional other materials, such as sewage wastes. Minimal research has been conducted on the application of FYW compost to agricultural crops in Nova Scotia, especially grain corn. Therefore results from the present study will be compared to findings from MSW composts, throughout this paper. Disparity between cited composts researched will be recognized due to many types of MSW composts resulting in similar and variable findings (Hargreaves *et al.,* 2008).

Throughout the province of NS there are 16 organic composting facilities, of which 12 primarily process FYW and of those 12, seven process the compostable materials in-vessel or in an enclosed reactor for control of air flow and temperature (Province of Nova Scotia, 2008). The Lunenburg Regional Recycling and Composting Facility and the Northridge Farms Composting Facility in Kings County process in-vessel FYW similarly; final products from both facilities are often similar in terms of their carbon to nitrogen ratio (C:N), pH, N and P content (Province of Nova Scotia, 2008). Hargreaves *et al.* (2009) studied the effect of Lunenburg's MSW compost on strawberries and concluded that it significantly increased soil Mehlich III extractable phosphorus (M3P) concentrations. These concentrations were found to increase with increasing MSW compost application rates. Fruit quality and yields were found to be reduced as a result of N deficient compost supplying inadequate amounts of N to the strawberries. Mkhabela and Warman (2005) also investigated this MSW compost as applied to potatoes and sweet corn grown in a Pugwash sandy loam soil. They concluded that MSW compost supplied amounts of P necessary for crop growth and increased soil P availability as well as its uptake by the two crops (Mkhabela and Warman, 2005). These results show the ability of MSW compost to supply adequate soil P while increasing the P uptake by vegetable crops, but that it may need to be supplemented with an additional N source (Mkhabela and Warman, 2005). Applications of FYW compost to supply P to crops, need to be further studied to quantify P fertilizer requirements and to explore the change in P uptake by crops.

Positive residual effects from both FYW and MSW composts have also been identified, such as increased soil organic matter (OM) content, nutrient availability and uptake by crops, and can be superior to those of residual manure and inorganic fertilizer applications. Rodd *et al.* (2000) investigated the residual effect of previous additions of MSW composts and found greater uptake by annual ryegrass and residual availability of N and P compared to previous manure applications. They also identified that repeated compost applications increased soil OM content and that grass yields increased with compost application rate (Rodd *et al*., 2000). Sullivan *et al.* (2003) investigated the residual effects of FYW compost and found similarly that N uptake by tall fescue grass and residual soil availability of N were both increased by previous additions of compost when compared to previous applications of inorganic fertilizer. This study monitored the residual effects of FYW compost for seven years and concluded grass yields were greatest during the second and third growing season and after seven years soil OM was also increased (Sullivan *et al.,* 2003). These findings identify the potential for residual benefits of both FYW and MSW compost applications to crops and soils.

In 2004, NS increased its organic waste diversion by 14% from 2002, resulting in over 93,000 tonnes of organic waste to be composted (Statistics Canada, 2008b). These composted organic materials have the potential to complement or partially replace over \$7.4 million $yr^{-1}$ of commercial fertilizers and lime, meeting the nutrient requirements of 819 $km^2$ fertilized agricultural crop land in NS, as was recorded in 2006 (Statistics Canada, 2009). As the number of FYW composting facilities in the province and Canada wide continue to grow and as composting technologies improve the capacity to produce a desirable product that may be suitable as a soil amendment increases accordingly. Further research needs to be documented on the qualities of compost sourced from FYW only and its potential use in agriculture as a source of crop nutrients.

## 2.2 Nutrients

### 2.2.1 Phosphorus

Phosphorus is a fundamental crop macronutrient that is required by plants for early plant growth, development of reproductive organs, crop maturity and root development (Karemangingo, 2004). Phosphorus is a necessary component of key molecules in plant growth including nucleic acids, phospholipids and adenosine triphosphate (ATP). Therefore, plants need a consistent supply of P to reach their potential yield (Schachtman *et al.*, 1998). Plant availability of P in soil is found in low concentrations, much of the P added to soils is rapidly ‘fixed’ into chemical forms and may not be available to plants (Burton *et al.,* 2003). Because it is so fundamental to plant growth and relatively unavailable in soils, P is applied to agricultural crop land, depending on availability of sources, either in the form of manure, inorganic fertilizer and/or alternative organic products (Lefebvre *et al*., 2005). Accurate estimation of the availability of applied P from these sources can be challenging based upon elements such as aluminum (Al), iron (Fe), manganese (Mn) and calcium (Ca) present in the soil, removal by plants, loss to leaching and erosion as well as in surface runoff. Therefore, soil P management requires consideration of these factors. Although the mobility of P in soils is limited, long-term application of manures or fertilizers has the potential to pollute groundwater in areas with shallow water tables or course textured soils (Sharpley, 1995).

### 2.2.2 Soil Phosphorus Cycle

Figure 2.1 illustrates the soil P cycle; the various forms of P and the pathways by which P may be taken up by plants or be lost to erosion and runoff. Burton *et al*. (2003)

described the soil P cycle as being made up of two large pools, organic P and inorganic P, including insoluble and soluble inorganic P (or plant-available P). Inorganic and organic P inputs to this cycle include plant residues, agricultural wastes, municipal and industrial by-products and fertilizers. These soil P inputs can be lost by processes such as erosion and runoff, or transformed by biochemical and chemical processes that result in their contribution to either the soil solution inorganic P pool, the organic P pool, the primary and secondary P minerals pools or the sorbed P pool. Plant-available P is released from the organic pool as a result of soil biochemical processes (mineralization) by soil microorganisms and from the inorganic pool via chemical processes (desorption and dissolution) (Figure 2.1). Phosphorus fixation is a transformation of soil P due to the reaction between soluble inorganic phosphates and other soil inorganic components. These P fixation reactions, sorption and precipitation, produce insoluble mineral compounds and make the native and applied soil P less available for plant uptake (Burton *et al.,* 2003). The ability of a soil to retain or 'fix' large amounts of P is important for reducing P loss to the environment and for subsequent transformation and plant uptake. Maintaining an appropriate soil pH (6.0-7.0) will help to improve the availability of soil and fertilizer added P and reduce the proportion of P that becomes 'fixed' (Burton *et al.,* 2003). Soil P pools and the associated soil processes are also influenced by many factors, including inputs and losses to leaching, erosion, and runoff which compound the challenge of predicting the amount of soil P that will be plant available throughout the growing season.

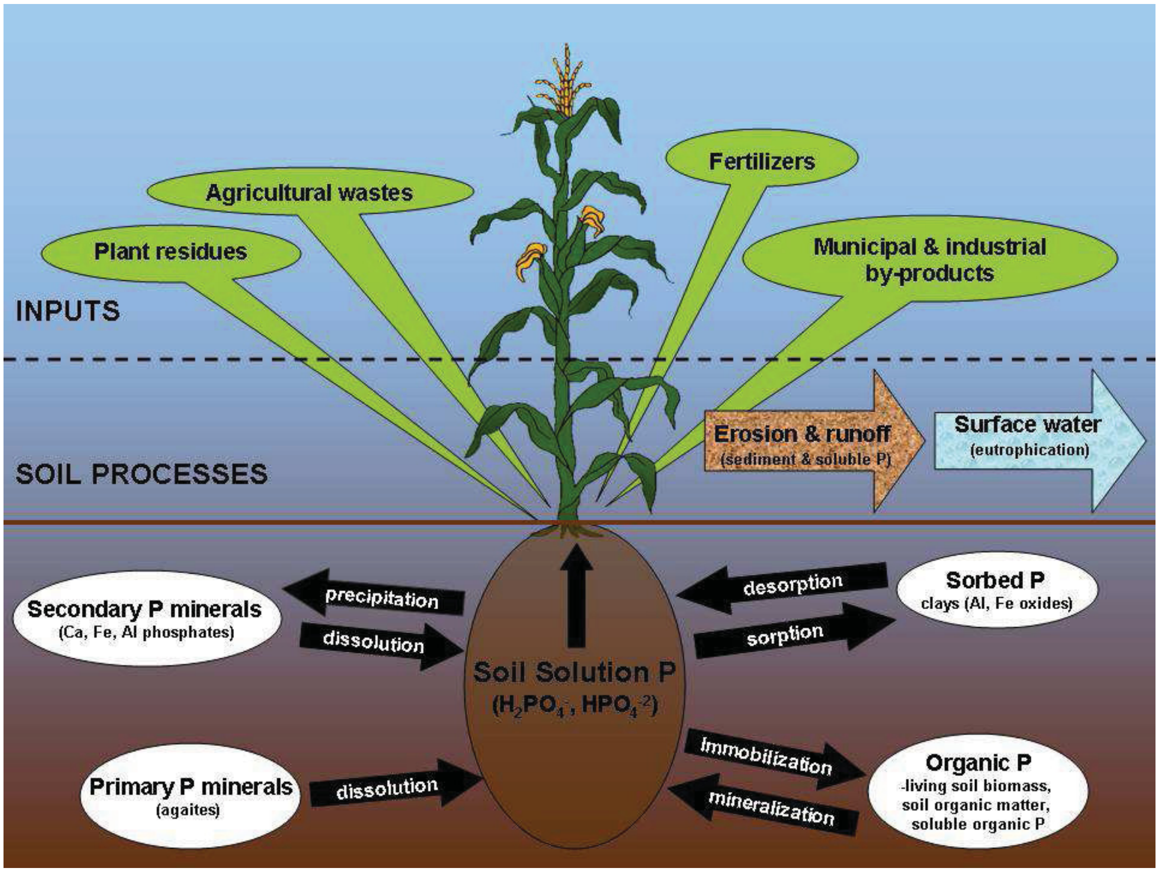

Figure 2.1 Depiction of soil phosphorus cycle (adapted from Pierzynski *et al.,* 2005).

### 2.2.3 Inorganic Phosphorus

Types of P in the soil available to plants for uptake include soluble phosphate ions in the form of di-hydrogen phosphate ($H_2PO_4^-$) and hydrogen phosphate ($HPO_4^{-2}$) (Burton *et al.,* 2003). A review paper by Sharpley (1995) on soil P dynamics reveals that, following P application in the form of manure, inorganic fertilizer and/or alternative organic products, plant available soil P increases as a function of physical and chemical soil properties. Specifically, these plant available forms of P are most available within a pH range of 6-7 (Burton *et al*., 2003) and are influenced by soils soluble Al, Fe, Ca and OM content (Sharpley, 1995). For example, in soils with low pH, soluble P reacts with Al and Fe to form compounds that precipitate out of the solution and at a higher pH, P reacts with Ca and forms precipitates and is less available to plants (Sharpley, 1995). Laboratory chemical soil tests are designed to extract the relatively soluble portion of the total P (TP) in the soil are found to correlate to plant uptake of P (Burton *et al.,* 2003). This soluble portion is often denoted ‘available P’, ‘soil test P’ or ‘M3P’ and is the sum of P in the soil solution and the P extracted from the soil by the chemical extractant, Mehlich III (Burton *et al.,* 2003). The M3P soil test is used in Atlantic Canada and involves using an Ammonium fluoride-Ammonium nitrate-Nitric acid-Acetic acid solution to extract the relatively soluble P and can be used for soils over a wide range of soil pH values (Burton *et al.,* 2003).

### 2.2.4 Organic Phosphorus

Various organic forms of P exist in the soil, representing 20-80% of the TP (Schachtman *et al.,* 1998) and can significantly contribute to the P nutrition of plants (Condron *et al*., 2005). As OM accumulates in soils, there is an increasing organic P portion of the TP in the soil (Condron *et al*., 2005). The turnover of organic P in the soil is ultimately determined by both the rates of immobilization and mineralization (Condron *et al*., 2005). Microbes carry out the process of P immobilization and the release of immobile forms of P to the soil solution (Schachtman *et al.*, 1998). Immobilization is the biological conversion of inorganic P to organic P by microbes; this more stable organic P is resistant to breakdown. Mineralization is the conversion of organic P into inorganic P in the soil through decomposition of plant and microbial residues by microbes (Figure 2.1). Inorganic P is generally considered to be the major source of plant available P in soils (Sharpley, 1995). Although contributions of organic P, the fuel for mineralization, are often considered to be equally important as it replenishes the soils pool of inorganic P (Sharpley, 1995). Compared to many other crops, the uptake and removal of plant available P is considerably higher by grain corn; 62-74 kg $ha^{-1}$ of $P_2O_5$ is removed in the harvested grain portion and not returned to the soil (Canadian Fertilizer Institute, 2001). Factors such as crop nutrient requirement, crop removal practices, plant available P within the soil, and soil physical and chemical characteristics need to be considered when making farm management decisions to minimize P build-up within the soil.

### 2.2.5 Phosphorus Pollution

Concern with P pollution of surface water is mainly due to its association with eutrophication. Controlling inputs is the main method in reducing this process (Sharpley, 1995). Eutrophication can occur when P lost from agricultural soils increases the fertility status of natural waters, accelerating the growth of algae and other aquatic plants (Burton *et al.*, 2003). Although N, P and carbon (C) are associated with accelerated eutrophication, P is often the most limiting nutrient. This is due to P being the element that is most limiting to aquatic plant growth and thus its addition is responsible for the greatest increase in aquatic plant growth, leading to eutrophication (Sharpley, 1995). Point sources of P pollution are easier to identify and control than non-point sources and therefore, result in less attention has been given to managing non-point sources (Sharpley, 1995). Factors such as soil type and soil M3P content are related to P leaching and when soil M3P exceeds crop removal the leaching of M3P increases with time (Zhang et al., 2004). Studies aimed at managing non-point sources of P pollution have found soil P content to be closely related to, and has an influence on, loss of P in drainage water and surface runoff (Sharpley, 1995). Reducing soil P accumulation, runoff and erosion will decrease the potential for transport of bioavailable P; therefore managing both the source of P and the potential transport of P out of a field is necessary for minimizing the risk of eutrophication (Burton et al., 2003).

### 2.2.6 Nitrogen

Nitrogen is a key plant nutrient; crucial in forming nucleic acids and proteins important for photosynthesis, cell wall composition, cell reproduction, energy and nutrient storage (Univ. Of Miss., 1993). This important element exists in many forms in the soil system, transforming from one form to another as influenced by various complex chemical and biological processes (Univ. Of Miss., 1993). Organic N, a component of soil OM in the form of decaying plant litter and soil organisms, and inorganic nitrate and ammonium are the most common forms of N found in the soil (Burton et al., 2003).

### 2.2.7 Nitrogen Cycle

The crop and soil N cycle provides N for crop uptake. The amount of N available for plant uptake is dictated by N gains through N fixation, mineralization and nitrification and N losses via denitrification, ammonia volatilization, immobilization and leaching (Cornell University, 2005). Nitrogen fixation describes the symbiotic relationship between legume roots and soil bacteria and results in the conversion of atmospheric $N_2$ to protein in the legume (Figure 2.2). When the legume dies the biologically fixed N is released to the next crop. Nitrogen fixation requires considerable energy from the plant therefore if plant available N exists in the soil, legumes will use it instead of fixing N. Nitrogen mineralization involves soil micro-organisms converting the organic N component of manure, crop residues, and soil OM to inorganic forms of N. These inorganic forms of N include ammonia ($NH_3$) and ammonium ($NH_4^+$) although; in acidic soils ammonia is quickly converted to $NH_4^+$. Nitrification involves microbes using enzymes to convert $NH_4^+$ to nitrite ($NO_2^-$) then quickly to nitrate ($NO_3^-$) to obtain energy (Burton et al., 2003). Due to the copious amount of $NH_4^+$ converting bacteria in the soil, $NO_3^-$ is often the most abundant plant available form of N in soil, and is readily taken up by crop plants (Cornell University, 2005). Both mineralization and nitrification depend upon soil temperature, moisture and aeration with the most rapid conversions occurring in warm, moist and well aerated soils (Cornell University, 2005). Denitrification describes the microbial conversion of $NO_3^-$ into various gaseous forms, including nitric oxide (NO), nitrous oxide ($N_2O$) and nitrogen gas ($N_2$), that are lost to the atmosphere, commonly found in poorly drained soils under wet conditions (Cornell University, 2005). Ammonia volatilization is the production and loss of the $NH_3$ gas from $NH_4^+$; this loss of $NH_3$ through volatilization is augmented by high soil pH and favourable evaporation conditions (Cornell University, 2005). Nitrogen losses via volatilization can be reduced by incorporating manure and/or urea fertilizer with or soon after application (Burton et al., 2003). Because soil microbes require N for their survival, they compete with crops for $NH_4^+$ and $NO_3^-$, this leads to a tie up of crop available N in microbial biomass, also called immobilization.

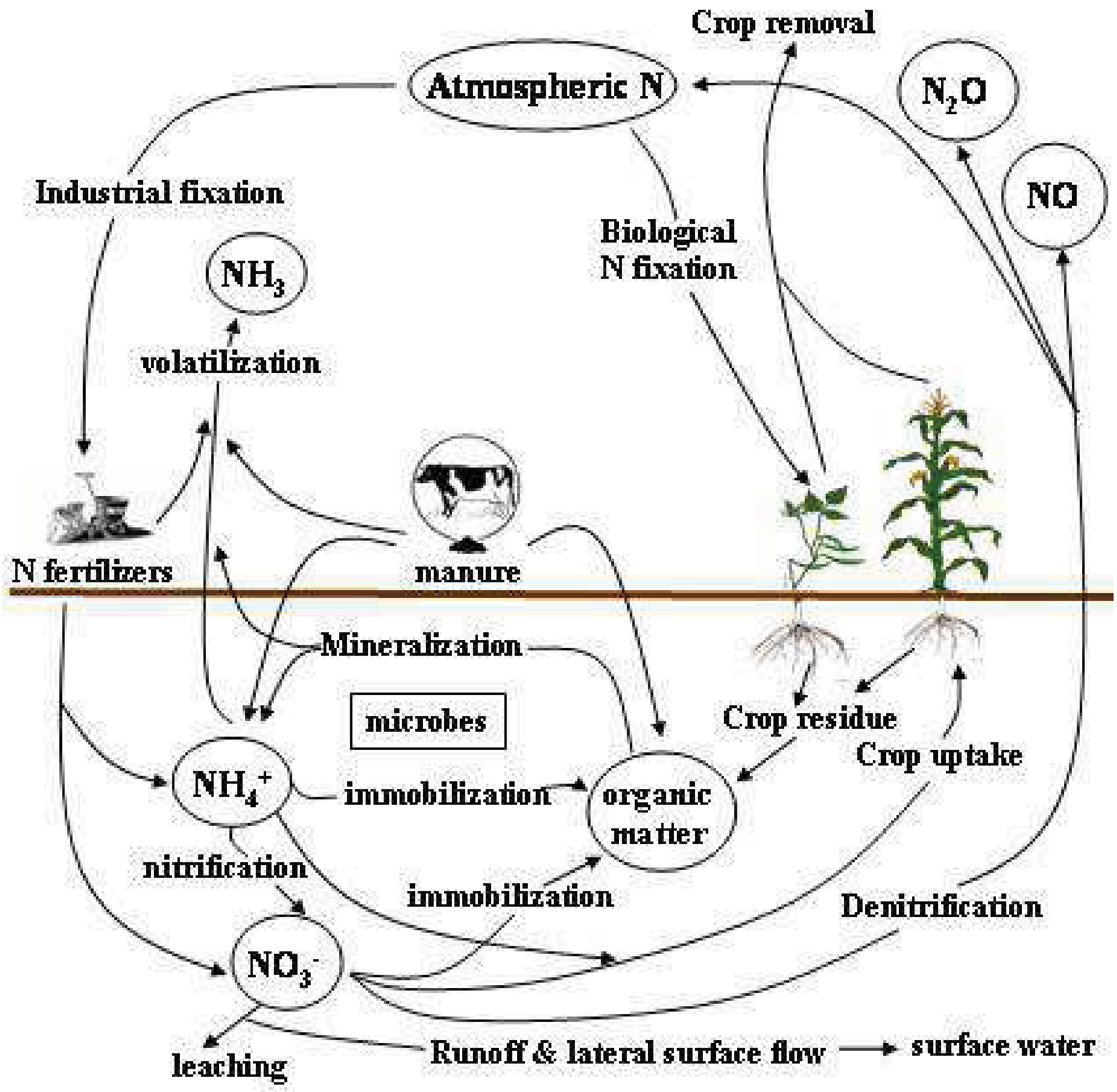

Figure 2.2 Soil nitrogen cycle (adapted from Cornell University, 2005).

One major pathway of N loss to the environment is leaching of nitrates; which occurs due to $NO_3^-$ negative charge and its inability to attach itself to soil particles, thereby easily "washing" away to below the root zone into surface and/or groundwater (Cornell University, 2005). The amount of nitrates lost to leaching depends upon soil drainage characteristics, rainfall, and the amount of $NO_3^-$ present in the soil.

Nitrogen is often a major limitation to crop yield since large amounts are removed through harvest every year and because it is the nutrient taken up in the greatest quantity by plants (Burton et al., 2003). Maximum crop N demands coincide with the most rapid growth period and most crops have a reduced requirement for N at the end of the growing season. Quite often, excess N is applied due to the difficulty in predicting the rate of various associated processes; which contribute to its loss through nitrate leaching, denitrification, ammonia volatilization and surface runoff and erosion (Burton et al., 2003). Therefore research is needed to assess FYW composts potential to supply plant available N and improve soil properties that may reduce the occurrence of both excessive application and subsequent surface runoff and erosion.

### 2.2.8 Nitrogen Pollution

Nitrates from rainfall, manures, N fertilizers and the decay of plants and other organic materials are of concern due to their high mobility with water in the soil (Univ. Of Miss., 1993). The concern with $NO_3^-$ and water quality is generally directed at groundwater where high levels of $NO_3^-$ can be toxic to human newborns, causing anoxia, or internal suffocation (Burton et al., 2003). Additionally, high levels of $NO_3^-$ in surface waters can contribute to the increased growth of blue-green algae or eutrophication. When the blue-green algae dies and breaks down in surface waters a depletion of oxygen ($O_2$) occurs which can lead to fish kills (Burton et al., 2003). The potential of $NO_3^-$ from animal manure and N fertilizers getting into groundwater can be reduced through good management practices (Univ. Of Miss., 1993). For example, applying N at recommended rates, adjusting rates to soil test results, application of N close to the period of maximum plant demand, employing split applications and utilizing fall cover crops are all methods of reducing N loss from cropping systems (Burton et al., 2003). Some areas of Canada utilize fall or spring $NO_3^-$ measurements to adjust application rates of N fertilizer but in humid regions of the country, there is no standard soil test for N due in part to the high chance of $NO_3^-$ loss over the fall-winter-spring period (Burton et al., 2003).

### 2.2.9 Phosphorus and Nitrogen in Corn Production

The uptake and removal of N and P by grain corn is greater than most other field crops due to its high yield potential and the amount of dry matter produced (Canadian Fertilizer Institute, 2001). Therefore, corn requires greater application of these nutrients to achieve desired yields in relation to most other field crops (Canadian Fertilizer Institute, 2001). Applying manure or compost to meet N requirements of corn can result in excessive amounts of applied P (Eghball and Power, 1999). This is partly due to manures supplying, on average, approximately three times as much P as N (Burton *et al.,* 2003) to a corn crop that takes up twice as much N as it does P (Canadian Fertilizer Institute, 2001). Notably, MSW composts are poor N suppliers and this inability to supply sufficient plant available N to meet requirements of high N demanding crops is one challenge with its agricultural use (Hargreaves *et al.,* 2008). Eghball and Power (1999) studied N and P uptake by corn and soil P levels over four years following composted manure applications and found that smaller, P-based, applications increased P uptake by corn and with less soil available P when compared to larger, N-based, applications (Eghball and Power, 1999). Mkhabela and Warman (2005) evaluated the influence of MSW compost on yield, soil P availability and uptake by corn and concluded that low availability of N in composted MSW may be addressed by supplementing N with an inorganic fertilizer. These mixture treatments of MSW compost and inorganic fertilizers resulted in higher total dry matter corn yields than inorganic fertilizers only or MSW compost only without increasing the soil M3P concentrations (Mkhabela and Warman, 2005). Phosphorus based applications of compost with additional N only fertilizers are necessary to avoid excessive P application to high N demanding crops such as corn.

## 2.3 Beneficial Management Practices

Potential environmental impacts of farming activities such as sediment and nutrient runoff into water bodies can be minimized by utilizing science-based farming activities or beneficial management practices (BMPs) (AAFC, 2007). Beneficial Management Practices are encouraged to support sustainable growth in farm business and can include composted manure**,** nutrient management planning (NMP) and soil erosion control management (NSDA, 2008). The environmental impact of agricultural runoff and the associated nutrient loading to surface waters have become a topic of interest in rural communities and watersheds (AAFC, 2007). As a result of this interest, the effectiveness of specific BMPs, at a watershed scale, in improving surface water quality, has been the aim of a nation wide study in seven watersheds across Canada over the past five years (AAFC, 2007). The Thomas brook watershed, in NS, is one of the watersheds currently evaluating BMPs, such as NMP, and their effectiveness on improving surface water quality (AAFC, 2007). A report on the nutrient and P status in the Thomas brook watershed has identified P as a concern in the watershed where over half of its land use is agriculture (Nunn, 2007). Phosphorus loss from agricultural soils is due primarily to runoff and erosion from soil with excessive P levels and results in the fertility status of natural waters that favour eutrophication (Burton *et al*., 2003). Managing the source of P is a key management consideration for reducing the loss of P and requires accurate assumptions of available nutrients from nutrient sources and soil amendments used for crop growth. Composted organic materials have been found to reduce P fixation in soils, increase soil pH and supply similar amounts of P as inorganic fertilizer (Mkhabela and Warman, 2005). Further investigation is required to determine whether FYW compost produced near the Thomas brook watershed may compliment NMP aimed at reducing P loss to surface water from agricultural soils.

# Chapter 3.0 Laboratory Incubation of FYW Compost to Quantify its P and N Contributions

## 3.1 Introduction

Compost made from food and yard waste (FYW) would mainly consist of decaying plant material or fully decomposed organic materials (ie. humus and/or organic matter (OM)) and as such can be expected to be a gradual source of the necessary micro- and macro- nutrients needed for plant growth (Stewart and Tiessen, 1987). Unlike inorganic fertilizers, the majority of nutrients in compost exist primarily in organic forms and require microorganisms for the conversion to plant available, inorganic forms. Macronutrients, such as Nitrogen (N) and Phosphorus (P), are required by plants in relatively large quantities and play important roles in plant growth and development, seed production (Univ. Of Miss., 1993), crop maturity and root development (Karemangingo, 2004). Current laboratory techniques quantify N and P contribution from soil amendments, such as compost and often involve a single inorganic nutrient content analysis. This method does not quantify the rate and quantity of subsequent organic N and P conversion in the soil and may be an under or over estimate of plant available nutrients, as contributed from the compost over the first and in subsequent growing seasons.

Organic N conversion by soil microorganisms involves the release of plant available ammonium ($NH_4^+$) through the process of mineralization or decomposition of organic material by microorganisms and is primarily related to soil temperature and water content (Univ. Of Miss., 1993). Nitrification is the further conversion of $NH_4^+$ to nitrate ($NO_3^-$) and proceeds rapidly in warm, moist, well-aerated soils (Univ. Of Miss., 1993).

Soil specific factors can affect N mineralization such as extreme wet or dry conditions can cause a decline in N mineralization and any increase in temperature can increase mineralization (Amlinger *et al.,* 2003). Therefore, specific factors should be monitored during incubations of composts to quantify contributions of plant available N.

Plant available P is released from the organic pool as a result of soil biochemical processes (mineralization) by soil microorganisms and from the inorganic pool via chemical processes (desorption and dissolution). The interactions among the biological, chemical and physical properties of the soil influence the dynamics of soil organic P (Stewart and Tiessen, 1987). Mineralization of compost's OM results in the release of organic P and this process is ultimately controlled by the balance of inorganic P availability and P demand by biomass and crops (Stewart and Tiessen, 1987). Major changes in soil temperature, available soil moisture and energy supply can all have negative effects on microbial biomass and activity or mineralization and immobilization processes (Stewart and Tiessen, 1987). Most of the total P (TP) in soils is not plant-available; therefore, in Atlantic Canada the Mehlich III soil test is designed to extract the relatively soluble portion of the TP from the soil and is used to estimate plant available P (Burton *et al.,* 2003). Phosphorus availability to plants is most often influenced by soil pH, soluble Aluminum (Al), Iron (Fe), Calcium (Ca) and soil OM content (Sharpley, 1995).

The concentration of macro-nutrients and their availability in municipal solid waste (MSW) composts varies depending upon its source of raw materials and length of composting time (Hargreaves *et al*., 2008). The supply of available N from biowaste and yard waste composts are dependent upon the carbon (C) to N ratio (C:N) of raw materials, composting conditions, post-treatment of compost, time of application and degradable amounts of C and N fractions (Amlinger *et al.,* 2003). Estimating the availability of compost N and P, when applying compost to meet nutrient requirements of various crops, is essential for effective nutrient management planning (NMP). The challenges associated with predicting availability of nutrients from composts will contribute to variability in application rates. Gagnon and Simard (1999) incubated various composts, including two types of FYW composts, to determine the impact of source materials and manure management on composts nutrient availability to plants. Their findings suggest that potential nutrient values of composts are dependent upon compost source materials and that, in the short-term, application rates should be based upon the inorganic N and P concentrations (Gagnon and Simard, 1999). Further knowledge of the relationship between the N and P concentrations in FYW compost and their plant availability over a growing season is essential for managing nutrients and maintaining yields.

Experiment 1 (E1) was a laboratory experiment intended to characterize the initial contribution of and subsequent conversion of mineral N and P from three FYW compost rates applied to a Pugwash loamy soil. This experiment was conducted under controlled temperature and humidity conditions with three compost rates and soil mixtures and a control each replicated three times and incubated and sampled over 88 d. A sub-sample was collected from each treatment repetition for the purpose of quantifying the mineralization rates of N and P as they became available in the soil and compost and soil mixtures. The aim was to better predict the release of nutrients from these particular compost soil mixtures over the growing season following application. These rates of release will enable more accurate prediction of nutrient release in the first year of application and potentially aid in predicting the availability of residual nutrients in the second year following application.

## 3.2 Materials and Methods

### 3.2.1 Soil

Soil was collected from the upper layer (0-15cm) of the Pugwash friable to firm coarse loamy soil located at a 7.5 ha field site within the Thomas brook watershed, Kings County, Nova Scotia (NS) (45.08 ° N, 64.75 ° W) in the spring of 2009. An assessment of 10 core sub-samples showed the soil had an average pH of 5.8 and bulk density of 1.28 g cm$^{-3}$. The physical and chemical characteristics of the soil used for this experiment are shown in Table 3.1.

Table 3.1 Initial physical and chemical characteristics of Pugwash soil.

| | |
|---|---|
| **Bulk density** (g cm$^{-3}$)** | **1.28** |
| **Organic matter** (%)* | **3.21** |
| **pH**** | **5.8** |
| **$P_2O_5$** (kg ha$^{-1}$)* | **269** |
| **$K_2O$** (kg ha$^{-1}$)* | **225** |
| **Ca** (kg ha$^{-1}$)* | **2573** |
| **Fe** (kg ha$^{-1}$)* | **437** |
| **CEC** (meq 100 g m$^{-1}$)* | **13** |

* Soil analysis reported values from the Nova Scotia Department of Agriculture, Quality Evaluation Services Laboratory in May 2009.
** Values averaged from a laboratory analysis of 10 sub-samples in May 2009.

### 3.2.2 Food and Yard Waste Compost Analysis

The source-separated FYW compost for this project was processed in-vessel and matured in windrows: materials were unloaded onto a conveyor belt where a magnet removed any metals, inorganics were separated manually and the remaining organic materials were then put through a grinder. The organics then began to decompose inside a covered enclosure where air was blown through the pile and temperature (45-60°C) was monitored. The pile was monitored for three weeks and the piles were turned three times. Following this initial process, the materials were transported to another building where the materials were windrowed on a cement floor for 15 weeks, to mature.

The compost used for this incubation was collected from a FYW composting facility located in Kings County, NS in the spring of 2009. Prior to treatment application in 2009, three 1 kg composite (6 sub-samples) compost samples were collected and submitted to the Nova Scotia Department of Agriculture, Quality Evaluation Services Laboratory for standard compost analysis. The elemental values, pH and dry matter were all averaged from the composite samples and can be found in Table 3.2.

Table 3.2 Main chemical properties of food and yard waste (FYW) compost.

| | |
|---|---:|
| **Dry matter** (%) | **54.0** |
| **pH** | **7.0** |
| **Total C** (%) | **23.5** |
| **Total N** (%) | **3.0** |
| **Total K** (%) | **3.1** |
| **C/N ratio** | **7.9** |
| **Total P** (%) | **1.0** |
| **C/P ratio** | **24.0** |
| **M3P** (%) | **2.3** |

### 3.2.3 Treatments

The treatments for E1 were: a soil only control (FYW0), 12 t $ha^{-1}$ compost (FYW0.5), 24 t $ha^{-1}$ compost (FYW1.0), and 36 t $ha^{-1}$ compost (FYW1.5), each replicated three times. These FYW compost treatment rates were chosen to enable comparison between their nutrient releases in the laboratory to those measured in the field, experiment 2 (E2). Both the compost and soil were air-dried and sieved through a 2 mm screen prior to treatment application. Each FYW treatment rate was added on 6 May 2009 (Day 0) to 250 g of soil and placed into containers for incubation. The 250 g of soil placed in the containers was determined to represent the volume of soil contained in a hectare furrow slice for the cylinders used in this experiment, based upon the bulk density of the soil used in the experiment. This volume of soil was used to determine the oven dry weight of compost to add to each jar for each treatment as shown in Appendix A (Honeycutt *et al*., 2005). Distilled water was added to all treatments to achieve 60 percent (%) water filled pore space (WFPS) and container lids, with small holes drilled to enable minimal air movement, were replaced and containers were placed in a dark incubator. Notably, the first sample day (Day 0) involved sampling the FYW compost and soil mixtures after incorporating both the distilled water and compost. The treatments were incubated from Day 0 to 88 (5 August 2009) with an incubation temperature of 25$^{o}$C, 80% humidity and 60% WFPS all maintained throughout the experiment (Honeycutt *et al*., 2005). Incubating treatments for 88 days at 25 $^{o}$C was employed to reflect the accumulation of corn heat units necessary for a grain corn crop grown in Atlantic Canada so as for results to be applicable to in-field applications.

On each sampling day and every three days in between, treatments were weighed to determine subsequent moisture losses; moisture adjustments were made when necessary (Honeycutt *et al*., 2005). At these times, the FYW compost and soil mixture containers were weighed and the difference in the mass since the last weigh-in were calculated and assumed to be due to moisture loss. Therefore an equal mass of distilled water was added to correct samples to 60% WFPS at each weigh-in. Sixty % WFPS was determined using the calculations found in Appendix A.

A sub-sample of 15 g was collected on seven occasions (0, 3, 7, 14, 28, 58, 88 d) from each treatment replication to determine pH, and the $NO_3^-$N, $NH_4^+$-N and M3P concentrations in extractions. The resulting $NO_3^-$N and $NH_4^+$-N and the M3P concentrations, as measured in sub-samples, were used to express the mineralized or plant available N and P, respectively. A sub-sample of 2.5 g, from each treatment replication, was extracted with 2 M KCl, filtered and the filtrate stored in a freezer. Subsequently the $NO_3^-$N and $NH_4^+$-N concentrations in the extracts were determined by ion chromatography according to standard methods of analysis (Maynard and Kalra, 1993) as adapted for the 8500 model Lachat instrument with methods 10-107-06-1-X (ammonia) and 10-107-04-1-A (nitrate) employed. A sub-sample of 2.5 g from each treatment repetition was extracted with the Mehlich III solution, filtered and the filtrate stored at 4°C; subsequently, TP was measured by colorimetry with an inductively coupled argon plasma spectrophotometer (ICAP) by standard method of analysis (Sen Tran and Simard, 1993). These analyses of extracted soil and compost mixture samples were conducted at the Crop and Livestock Research Centre in Prince Edward Island. The remaining 10 g of each sub-sample were used to determine pH of soil and soil and compost mixtures.

### 3.2.4 Data Analysis

Treatment sample properties, including pH and concentrations of M3P, $NO_3^-$-N and $NH_4^+$-N, were measured and recorded for each sample date over the 88 d incubation. Concentrations of M3P and mineral N ($NO_3^-$-N plus $NH_4^+$-N) were reported as mg $kg^{-1}$ and represented the mineralization of plant available P and N from the FYW compost, respectively. The release rates of plant available N and P were determined by calculating the change in concentrations of M3P and mineral N between sample dates. To determine the total contribution of plant available N and P from the FYW compost only, mineral N and M3P concentrations measured in the soil only control on Day 0 were subtracted from those measured in the soil-compost mixtures at Day 88. Concentrations of mineral N were multiplied by the FYW compost application rates (kg $ha^{-1}$) to determine the mass (kg) of plant available N mineralized by each treatment rate. The percent (%) N mineralized of the total N added by the FYW compost was calculated by dividing the concentration of mineral N measured on d 88 (less the initial mineral N concentration measured in the soil only control) by the concentration of total N measured to be in the FYW compost prior to the incubation. Concentrations of M3P were multiplied by the FYW compost application rates (kg $ha^{-1}$) to determine the mass (kg) of plant available P mineralized by each treatment rate. The % plant available P mineralized over the 88 d incubation was determined by dividing the mg $kg^{-1}$ of M3P on d 88 (less the initial M3P concentrations measured in the soil only control) by the M3P concentration of the FYW compost application rates (Gagnon and Simard, 1999).

### 3.2.5 Statistical Analysis

The control and soil and compost mixture treatments were replicated three times across the four levels of compost (FYW0, FYW0.5, FYW1.0 and FYW1.5) for each of the seven sampling days and analyzed as a randomized block model. A second degree polynomial curve was used to fit lines to the measurements of M3P, $NO_3^-$-N and $NH_4^+$-N for all treatments; evaluating the rate of change and difference between treatment responses. This model revealed curves with similar slopes, rates of release, and allowed separation of curves depending upon the rate of compost applied. A stepwise regression analysis was performed to determine whether FYW compost application, or the rate it was applied, had a significant effect on the net N and P mineralized over the 88 d incubation.

## 3.3 Results and Discussion

Results in regards to the availability of N and P are presented in the following subchapters with recommendations to follow. Notably, contributions of plant available N and P on Day 0 from all treatments reflects amounts of N and P having had mineralized in the soil and compost prior to the incubation experiment.

### 3.3.1 Net Nitrogen Contribution

Results showed a statistically significant positive response to FYW compost application with higher concentrations of plant available N measured in soil and compost mixtures on Day 0 than when compared to a soil only control ($p<0.001$) (Figure 3.1). The higher concentrations of plant available N contributed by FYW compost represents N mineralized in the compost prior to the incubation. Notably, 65-69% of the plant available N contributed, over the 88 d incubation, by the FYW compost soil mixtures was plant available on Day 0, which immediately followed incorporation of the FYW compost into the soils (Table 3.3). Similar to these results, a test of 23 types of waste material compost and soil mixtures revealed that 88% of the plant available N, that accumulated over a 13 week incubation, was available in the first 5 weeks (Amlinger *et al.,* 2003). Giusquiani *et al.* (1988) conducted a long-term (12 months) incubation of urban waste compost and sandy loam and clay silt loam soil mixtures. This urban waste compost was composed of similar raw materials, had similar N, P and C concentrations and comparable pH as the FYW compost used in E1. Giusquiani *et al.* (1988) reported an increase in the percentage of total N caused by the compost addition at time 0 with no additional significant increases in N mineralization measured in subsequent samples collected at 4, 8 and 12 months. Therefore, greater amounts of plant available N measured in FYW treatments on Day 0 can be attributed to the addition of compost reflecting the amount of plant available N that had previously mineralized in the compost. The plant available N concentrations showed a trend to increase with increasing FYW compost application rates although no statistically significant difference was found between the compost application rates. Growers incorporating FYW compost into their nutrient regime should time applications appropriately with high nutrient demanding crop growth stages. Also, quantifying amounts of plant available N in FYW compost prior to its incorporation into soil would provide a more accurate estimate of composts immediate N contribution to the soil.

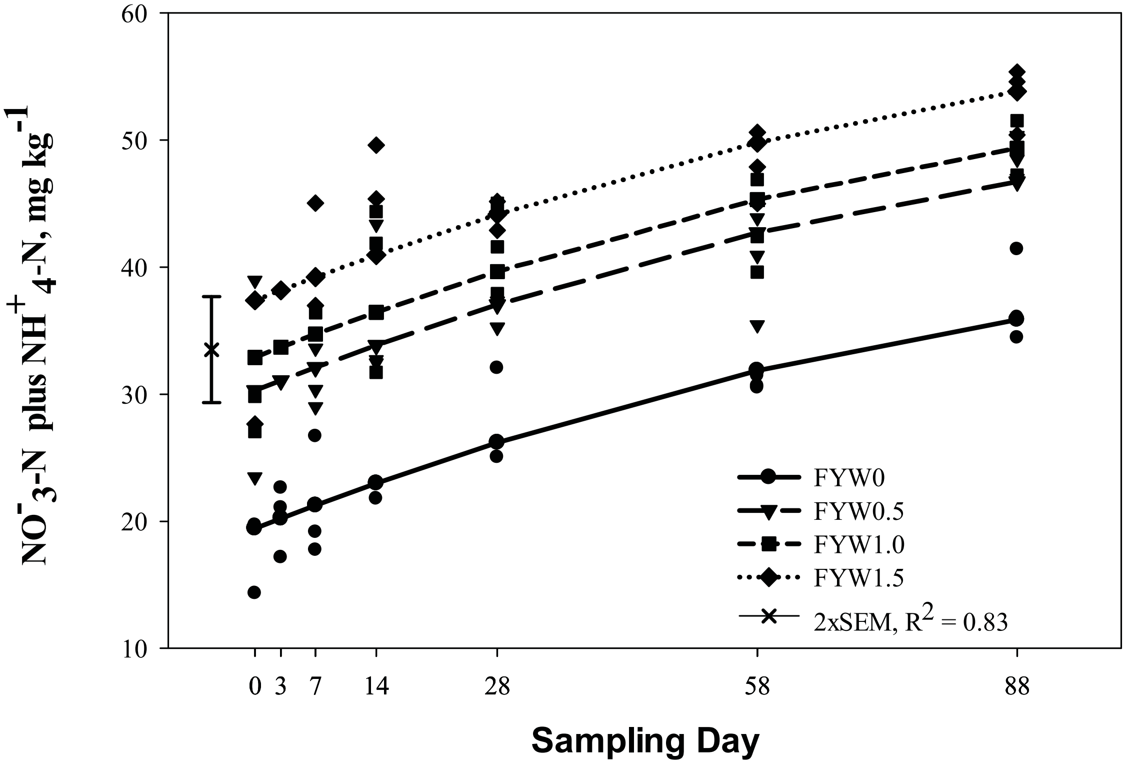

Figure 3.1 Change in concentration (mg kg$^{-1}$) of mineral-N ($NH_4^+$-N plus $NO_3^-$N) over an 88 d (May 6 – August 5, 2009) incubation of soil only and food and yard waste (FYW) compost and soil mixtures.

Table 3.3 Concentrations of M3P and mineral N ($NO_3^-$N plus $NH_4^+$-N) measured in incubated food and yard waste (FYW) compost and soil mixtures as expressed on a mg nutrient kg$^{-1}$ compost basis over 88 days.

| | **FYW0** | | **FYW0.5** | | **FYW1.0** | | **FYW1.5** | |
|---|---|---|---|---|---|---|---|---|
| | M3P | Mineral N | M3P | Mineral N | M3P | Mineral N | M3P | Mineral N |
| **Sample Day** | mg nutrient kg$^{-1}$ food and yard waste compost | | | | | | | |
| 0 | 1200 | 19.42 | 1417 | 30.28 | 1733 | 32.9 | 2004 | 37.38 |
| 3 | 1217 | 20.22 | 1413 | 31.07 | 1740 | 33.69 | 2053 | 38.17 |
| 7 | 1239 | 21.25 | 1407 | 32.1 | 1750 | 34.72 | 2114 | 39.2 |
| 14 | 1276 | 22.98 | 1399 | 33.84 | 1766 | 36.45 | 2208 | 40.94 |
| 28 | 1341 | 26.18 | 1393 | 37.04 | 1793 | 39.65 | 2353 | 44.14 |
| 58 | 1448 | 31.84 | 1420 | 42.7 | 1827 | 45.31 | 2462 | 49.8 |
| 88 | 1507 | 35.86 | 1501 | 46.72 | 1830 | 49.34 | 2296 | 53.82 |
| **Day 88 – Day 0** | **307** | **16.44** | **84** | **16.44** | **97** | **16.44** | **292** | **16.44** |

Statistically, the net 88 d contribution of plant available N was greater for all the FYW compost treatments than the control ($p<0.001$) (Figure 3.1). Although, the rate of N mineralization, over the 88 d experiment, did not vary statistically between the FYW compost treatments and the soil only control (Figure 3.1). These findings indicate that the FYW compost did contribute significantly greater amounts of plant available N then the soil but that the fractions of organic N in the compost did not mineralize at a faster rate than that of the organic N fraction of the soil. Gagnon and Simard (1999) noted a significant linear relationship between organic N mineralized and the biodegradability of C in compost, finding increased N mineralization with more mature composts. The initial incorporation of FYW compost on Day 0, or contribution of biodegradable C as associated with a low C:N (7.9)contributed the most significant amount of plant available N. The net N mineralization was not found to be statistically significantly greater when larger amounts of compost were applied, for this particular suite of FYW compost application rates. These results indicate that applications of FYW compost can be expected to make approximately two thirds its contribution of plant available N to the soil at incorporation and that the organic N fraction of the compost mineralizes at a similar rate over the growing season as that of this coarse loamy soil. These results further corroborate that FYW compost should be applied and incorporated into the soil just prior to planting and that subsequent applications should coincide with crucial plant growth stages to ensure a plants optimum use of N and to minimize N loss to leaching and runoff.

A mere 0.09 – 0.11 % of the total N added by compost mineralized as $NO_3^-$N and $NH_4^+$-N or became plant available from FYW compost and soil mixtures over the 88 d

(Table 3.4). Similar findings were documented by Giusquiani *et al.* (1988) who reported between 0.12 – 0.21% of N release, from the total N measured in an urban waste compost. Gagnon and Simard (1999) conducted a 13 week incubation experiment, to determine N and P release from on-farm and industrial composts, where composts were incubated at 35°C for 13 weeks at 75% WFPS. Poultry manure compost within this study most closely reflected N, P and C content of the FYW compost used in the present study and resulted in 8.1% of total N mineralized (Gagnon and Simard, 1999). Furthermore, Amlinger *et al.* (2003) reviewed an experiment on 38 different yard waste composts and reported that, the mineralization of total compost N was between -11 and 8.1% with an average of 2.1%. This review of the N dynamics of biowaste and yard waste composts concluded that following five different incubations studies, 12-52 weeks in duration with optimum temperature and water content maintained, only one experiment found a N mineralization rate of greater than 15% (Amlinger *et al.,* 2003). Amlinger *et al.* (2003) carried out various incubation and field tests and determined that factors that affected the mineralization of N in compost and soil mixtures were the availability of C and N (quantity and solubility), C:N, and soil texture and water holding capacity. Considerable variability exists within the literature; therefore, results from E1, that 0.1% of the total N from this FYW compost mineralized in the first 88 d, should be assumed when applications are made between 12 and 36 t ha$^{-1}$ to sandy loam soils. Considering the biodegradability of this FYW compost, based upon parameters such as its C:N ratio of 7.9 and considering the trend for continued mineralization exhibited by all treatments (Figure 3.1); the mineralization of plant available N can be expected to occur in the subsequent growing seasons. Amlinger *et al.* (2003) review concludes that when the immediate N-effect was less than 15% of the total N supplied by compost then further contributions of 2-8% year$^{-1}$ of the remaining compost N are expected. Carrying out laboratory incubations of FYW compost only and mixed with soil over a longer period of time will facilitate further comprehension of plant available N contributions past the first growing season. Also, further laboratory experiments should include quantifying total N at the end of the incubation to quantify amounts of nitrogen lost to denitrification and ammonia volatalization.

Table 3.4 Total mg plant available P and N mineralized per kg compost, total kg of plant available P and N mineralized by treatment, 88 d cumulative % M3P mineralized as added by compost and % mineral N ($NO_3^-$N plus $NH_4^+$-N) as added by total compost N.

| **Plant available nutrient** | **Treatment** | Total mg kg$^{-1}$ at Day 88 | Mass (kg) of nutrient mineralized | % mineralized of applied |
|---|---|---|---|---|
| Mineral N | FYW0 | **16.4** | **n/a** | **n/a** |
| | FYW0.5 | **27.3** | **0.33** | **0.09** |
| | FYW1.0 | **29.9** | **0.72** | **0.10** |
| | FYW1.5 | **34.4** | **1.24** | **0.11** |
| M3P | FYW0 | **307** | **n/a** | **n/a** |
| | FYW0.5 | **301** | **3.61** | **1.34** |
| | FYW1.0 | **630** | **15.12** | **2.80** |
| | FYW1.5 | **1096** | **39.46** | **4.87** |

Although the most substantial contribution of plant available N from the FYW compost treatment mixtures occurred at initial incorporation, results from this study show that further N mineralization did occur over the 88 d incubation. The net N contribution at Day 88 was significantly greater than amounts of mineralized N at Day 0 for all treatments ($p<0.001$) (Figure 3.1). The lowest FYW compost application rate mineralized amounts of accumulated plant available N similar to that of the soil only control.

Statistically, significantly higher amounts of plant available N were measured in the 24 and 36 t $ha^{-1}$ application rates than when compared to 12 t $ha^{-1}$ or the soil only control (2xSEM=8.34). Application rates of 12, 24 and 36 t $ha^{-1}$ FYW compost incorporated into the sandy loam soil supplied a total of 0.33, 0.72 and 1.24 kg inorganic N $ha^{-1}$ in the first three months following application, respectively (Table 3.4).

Statistically, the rate and net release of mineral N over the 88 d did not vary significantly between FYW compost application rates. Nitrogen mineralization increased at every sampling interval with a trend for it to continue past the period of incubation; therefore, exhibiting the potential for additional contributions of nutrients to the soil past 13 weeks ($p<0.001$) (Figure 3.1). Factors such as C and N content, the associated C:N, compost maturity and source of materials composted determine the net N mineralization and timing of release from organic waste composts (Amlinger *et al.*, 2003; Chae and Tabatabai, 1986; Gagnon and Simard, 1999; Mamo *et al.*, 1998). Small increases in soil pH, as seen in this experiment, induced by rewetting and drying may stimulate mineralization of soil organic N (Chepkwony *et al.,* 2001). Although, this matter is disputed by Amlinger *et al.* (2003) who reports that pH only inhibits mineralization at levels of <5 and >8. Giusquiani *et al.* (1988) documented that the initial release of N, caused by compost addition, remained practically constant with a slight decrease past four months of incubation. Chae and Tabatabai (1986) documented N mineralization from dried plant materials added to soils to follow a fast initial rate up to 12 weeks with a steady N release between 12-26 weeks. The continued N mineralization identified in E1 over 13 weeks requires further investigation to identify the further release of N that may contribute to future growing seasons. Results from E1 suggest that the FYW compost does not mineralize sufficient amounts of plant available N to support the growth of a corn crop over the 13 weeks, but resulting supplemental amounts should still be considered for nutrient management purposes.

### 3.3.2 Mehlich III Extractable Phosphorus

The availability of P in FYW compost treatments and the soil only control over the 88 d incubation is illustrated in Figure 3.2. Statistically, FYW compost contributions to soil did not result in significantly greater availability of P on Day 0 than the soil only control. Sampling on Day 0 immediately followed treatment preparation and as such the availability of P on Day 0 reflects the P already mineralized in the soil and FYW compost prior to incubation. Statistically, on an individual basis, the application rates of 24 and 36 t ha$^{-1}$ of FYW compost (FYW1.0 and FYW 1.5, respectively) did show, significantly greater concentrations of M3P on Day 0 than the soil only control (SEM=280) (Figure 3.2). Findings from a study evaluating MSW compost applications to a Pugwash sandy loam soil in Nova Scotia identified their highest compost application rate to result in greater M3P concentrations than when compared to NPK fertilizer only or MSW compost and NPK fertilizer mixtures (Mkhabela and Warman, 2005). These MSW compost application rates, 11.3, 22.6 and 33.9 t ha$^{-1}$, were similar to the present study with findings also indicating that all MSW compost and MSW compost and NPK fertilizer mixture treatments resulted in equivalent amounts of total soil P as the NPK fertilizer (Mkhabela and Warman, 2005). Hargreaves *et al.* (2008) reviewed two studies that found MSW compost applications to increase soil P concentrations and that the availability of P increased with increasing application rates. Results from E1 indicate that applying 24 or

36 t ha$^{-1}$ of FYW compost to a Pugwash sandy loam soil can contribute significantly greater amounts of plant available P than applying FYW compost at a rate of 12 t ha$^{-1}$.

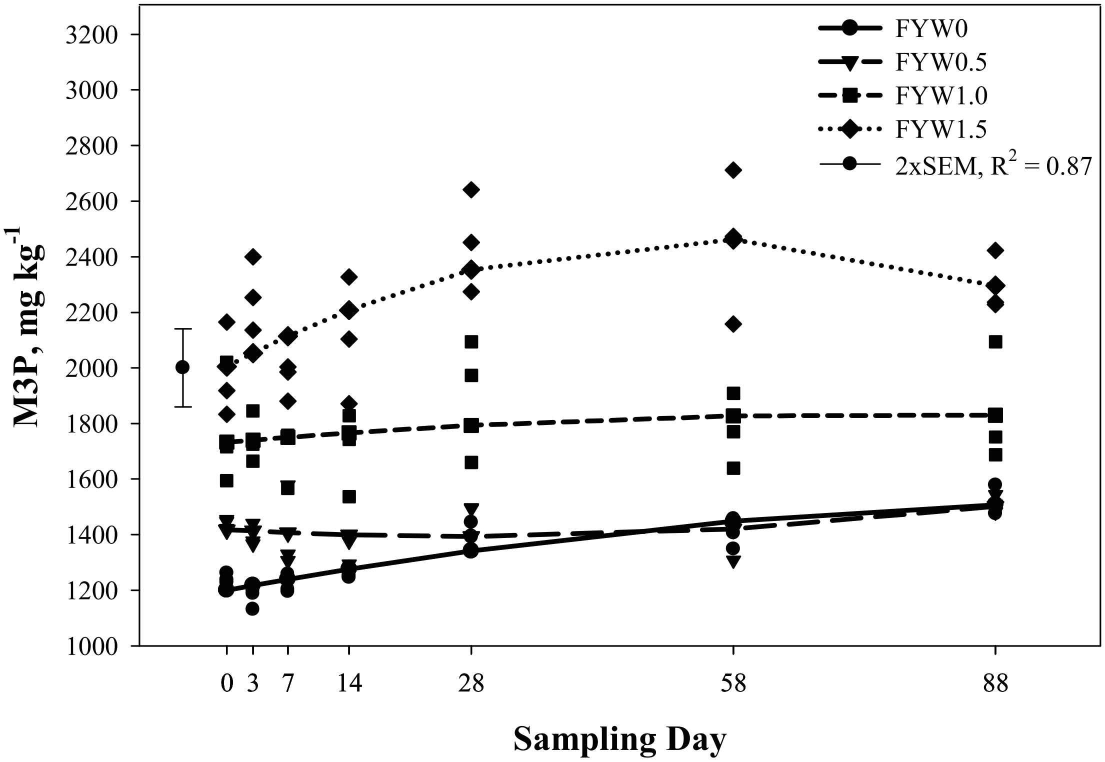

Figure 3.2 Change in concentrations (mg kg$^{-1}$) of Mehlich III extractable phosphorus (M3P) over an 88 d (May 6 – August 5, 2009) incubation of soil only and food and yard waste (FYW) compost and soil mixtures.

The rate of P mineralization was steady over the 88 d incubation for all treatments, indicating that the release of P from the FYW compost was stable. Gagnon and Simard (1999) also concluded the net P in soils, amended with industrial and on-farm composts, did not change very much over a 13 week incubation. Findings from E1 identify that there was no statistically significant decline in the release of P from any treatment or the soil only control but treatment FYW1.5 did show a trend to decrease following sample collection on Day 58. A more long-term incubation of this FYW compost and soil mixtures may more accurately determine the availability of P over an entire growing season.

On average for all FYW compost treatment application rates, the change in the amount of plant available P measured between Day 0 and Day 88 did not differ significantly from that of the soil only control. Although individually, the data shows that the availability of P in the FYW0 and FYW1.5 treatments increased significantly over the 88 d (2xSEM=280) in comparison to FYW0.5 and FYW1.0 which did not significantly change (Table 3.4). A linear trend was identified between the availability of P in the soil-compost mixtures over the 88 d incubation and the FYW compost application rate (p=0.023) (Fig 3.2). Results indicated that 0.30, 0.63 and 1.10 kg M3P $t^{-1}$ FYW compost were mineralized respectively from FYW0.5, FYW1.0 and FYW1.5 treatments (Table 3.3). FYW0.5, FYW1.0 and FYW1.5 mineralized 1.34, 2.80 and 4.87 % of P added from compost respectively, which correlates to P available for plant uptake. Gagnon and Simard (1999) found the net P mineralization in soil and compost mixtures was related to the total P in composts and that P mineralization did not change considerably after the third week of incubation. The lack of net change in P concentrations can be attributed to P transformation processes (immobilization and mineralization) occurring simultaneously in the soil (Holford, 1997). Mineralization of organic P is controlled by the balance of inorganic P availability and the P demand of biomass and crops and subsequent mineralization of organic matter which releases organic P as a by-product (Stewart and Tiessen, 1987). Mkhabela and Warman (2005) found that their research of MSW compost applied to sandy loam soils growing corn and potatoes suggested MSW compost to supply similar amounts of P as inorganic fertilizer. Notably, increases in plant available P concentrations in the soil is triggered by P removal from the solution by root adsorption or by soil process ie. sorption (Holford, 1997). Therefore a better estimate of plant available P contributions from FYW compost may be identified by including the removal of P by plants throughout similar laboratory experiments as E1.

Current recommendations by nutrient management planners include the placement of 15-25 kg ha$^{-1}$ of readily available P fertilizers in a band next to the seed at planting for early corn growth and root development (VanRoestel, 2009b). The results from E1 indicate that supplies of P from FYW compost application rates among 12, 24 and 36 t ha$^{-1}$ are equivalent to 3.6, 15.1 and 39.5 kg plant available P, respectively, as gradually released over a 13 week incubation (Table 3.3). Notably, the gradual availability of P measured in treatment FYW1.5 suggests that applying this FYW compost rate to soil prior to planting may eliminate the requirement for suggested applications of inorganic P fertilizers at planting. Incubation experiments, such as E1, allow for control of parameters such as temperature and soil moisture that contribute to optimum growing conditions; therefore, conditions in the field will vary from season to season as will the dynamics of P and N mineralization from FYW compost.

### 3.3.3 pH

Over the course of the 88 d incubation the pH did not vary significantly between the FYW and soil mixtures and the soil only control. Giusquiani *et al.* (1988) reported no change in pH of their incubated soil and compost mixtures over a 12 month period. Interestingly though the incubated treatments exhibited a statistically significant increase in soil pH over the first 28 d, followed by a small increase until Day 58 with a significant decrease over the last 30 d (2xSEM=0.62). This response is attributed to the incorporation of the FYW compost which had a neutral pH into the soil which had a slightly acidic pH and/or by the drying and rewetting of treatments (Chepkwony *et al.,* 2001). Drying and rewetting of incubated soils can cause changes in mineralization of plant available P and N and, as a result, changes in soil pH are often noted (Chepkwony *et al.,* 2001). Results from the laboratory experiment, E1, imply that FYW compost will not decrease or may maintain the pH of the soil to which it is applied.

Table 3.5 Change in pH of soil and soil and food and yard waste (FYW) compost mixtures over an 88 day laboratory incubation with comparison of resulting means (means highlighted in bold are significantly different than NPK treatment, based upon 2 x SEM).

| | **Treatment** | | | |
|---|---|---|---|---|
| **Sample Day** | **FYW0** | **FYW0.5** | **FYW1.0** | **FYW1.5** |
| 0 | 5.43 | 5.48 | 5.46 | 5.47 |
| 3 | 5.54 | 5.58 | 5.56 | 5.57 |
| 7 | 5.66 | 5.71 | 5.69 | 5.70 |
| 14 | 5.85 | 5.90 | 5.88 | 5.89 |
| 28 | 6.12 | 6.16 | 6.14 | 6.16 |
| 58 | 6.19 | 6.23 | 6.21 | 6.22 |
| 88 | 5.56 | 5.60 | 5.58 | 5.59 |
| **Mean** (SEM=0.31) | 5.76 | 5.81 | 5.79 | 5.80 |

## 3.4 Conclusion

Results from E1 are that treatments FYW0.5, FYW1.0 and FYW1.5 can be expected to contribute greater amounts of plant available N than soil only. Also, the availability of P from treatments FYW1.0 and FYW1.5 can be expected to be greater than soil only at application, with a steady release over the 88 d for all treatments. This initial increase in plant available N and P is attributed to the initial N and P content of the compost and its transformation through mineralization processes during the composting process prior to incubation. The short-term contribution of plant available N from FYW compost is not considered to be substantial, 0.1% of the total N added by compost, but amounts should be considered for nutrient management purposes.

Applying FYW compost at rates between 24 and 36 t $ha^{-1}$ can be expected to significantly increase the availability of P at the time of application. Residual, less substantial, amounts of plant available P as contributed over the growing season should also be considered. Contributions of plant available P, on average, did not increase with increasing FYW compost application rates when compared to the soil only control. Although, the greatest FYW compost application did have a more significant effect on plant available P than the soil only control therefore, when applications are made to crops, rates should be based upon P requirements to limit over-applying P. Quantitatively, FYW compost applied at rates of 12, 24 and 36 t $ha^{-1}$ incorporated into the sandy loam soil resulted in N supply of 0.33, 0.72 and 1.24 kg inorganic N, respectively. This incubation experiment identified plant available P contributions from FYW compost, over 88 d, can equate to 3.6 kg from FYW0.5 or 12 t $ha^{-1}$, 15.1 kg from FYW1.0 or 24 t $ha^{-1}$ and 39.5 kg from FYW1.5 or 36 t $ha^{-1}$. The supply of plant available P from the 36 t $ha^{-1}$ FYW compost would meet P removal requirements of grain corn.

The availability of P from FYW compost can be expected to be steady over the growing season and may be better suited to respond to a crops shifting nutrient demands over the growing season, when compared to readily available inorganic fertilizers. The contributions of both plant available N and P from the FYW0.5, FYW1.0 and FYW1.5 treatments should be included in nutrient balances for crop production. By measuring concentrations of mineral N and M3P only, gaseous losses of N and immobilization of both N and P could not be quantified. Future incubation experiments should include measuring total N and P at the end of the experiment to gain a better understanding of the fate of FYW composts total N and P. Food and yard waste compost applications aimed at meeting the P requirements of crops, supplemented with an additional source of N, are recommended to eliminate excessive application of P.

# Chapter 4.0 Effects of FYW Compost Application on Grain Corn and Soil Characteristics

## 4.1 Introduction

Phosphorus (P) is a fundamental crop nutrient required for early plant growth, development of reproductive organs, crop maturity and root development (Karemangingo, 2004). Mehlich III extractable P (M3P) correlates to the amount of P in the soil available for plant uptake. Mehlich III extractable P is impacted by leaching and erosion of organic and inorganic P, crop removal of P, mineralization of organic P and the addition of P in the form of inorganic fertilizers, animal manure, and composts (Burton *et al.*, 2003). The availability of P in the soil to crops is most often influenced by soil pH, soluble aluminum (Al), iron (Fe) and calcium (Ca), and the organic matter (OM) content of the soil (Sharpley, 1995). Specifically, a low pH results in soluble P reacting with Al and Fe to form compounds that precipitate out of solution and a higher pH causes P to react with Ca to form less plant available precipitates (Sharpley, 1995).

Kings County is known as Nova Scotia's (NS) largest agricultural producing county, making up 15.9% of all farms in NS, 12.2% of total farm area and accounts for 33.5% of all gross farm receipts in the province (NSDA, 2010). The majority of agricultural soils in Kings County are used for forage and grain production and contain adequate levels of M3P to produce optimum yields with 73% of soils below the optimum pH of 6.5 (LeBlanc *et al.,* 2006; LeBlanc*,* 2008). Even though levels of M3P may be sufficient for optimum crop yields, more than 80% of the P in agricultural soils becomes immobile and unavailable to plants (Schachtman *et al.*, 1998); therefore, additional P in the form of manure, inorganic fertilizer or alternative organic products are applied to support the high growth rate of crop plants (Lefebvre *et al*., 2005).

Concern with P pollution of surface water is mainly due to its association with eutrophication (Sharpley, 1995). Non-point source pollution of P to surface waters occurs when soil P levels are in excess of crop requirements and conditions exist that favour the loss of P through agricultural drainage and surface runoff (Sharpley, 1995). Research has shown that compost application can reduce the phosphorus loss from soils by improving soil properties (Spargo *et al.,* 2006; Wortmann and Walters, 2007).

Nova Scotia's ban in 1998 on household organic waste from entering their waste stream lead to the production of local, stable, organic municipal solid waste (MSW) composts; recently being applied to soils as an amendment, and source of nutrients (Province of Nova Scotia, 2008). Municipal solid waste compost's high organic matter and low bulk density make it appealing as a soil amendment and research has shown its ability to increase soil organic matter (OM) content (Rodd *et al*., 2000), soil pH (Mkhabela and Warman, 2005; Rodd *et al*., 2000) and the growth and yield of vegetables (Ozores-Hampton *et al.,* 1994; Warman *et al.,* 2009). Composting transforms organic by-products into drier, more uniform and more biologically stable products therefore, slowly releasing plant-available N and P (Burton *et al.,* 2003; Sullivan *et al*., 2002). The concentration of nutrients and their availability in composts have been found to vary according to the source of feedstocks and length of composting time; contributing to variability in nutrient application rates with compost (Hargreaves *et al*., 2008). The variability in FYW compost's ability to supply plant available N and P (Amlinger *et al.,* 2003; Chae and Tabatabai, 1986; Sullivan *et al.,* 2002) confirms the need to quantify rates of and net nutrient supplies from NS's FYW compost to determine appropriate application rates.

The uptake and removal of N and P by grain corn are greater than most other field crops and often require considerable application of nutrients to achieve desired yields while minimal nutrients and OM are returned through crop residue (Canadian Fertilizer Institute, 2001). Applying manures and composts to meet crop nutrient requirements is often challenging because the availability of nutrients is highly variable (Burton *et al.,* 2003). Traditionally, the application of manures and composts to agricultural crops has been based upon the N requirements of a crop and results in excessive M3P for agricultural production (LeBlanc, 2008). Mehlich III extractable P build up, in agricultural land under grain corn production, is often a result of the plant available N:P ratio of manures and composts being significantly smaller than that of N:P ratio uptake of corn (Eghball and Power, 1999). Therefore, more appropriately, application rates of manures or composts are aimed to supply necessary amounts of P and if additional N is needed it is supplied with inorganic fertilizers. With 12,000 acres of agricultural land harvested as grain corn in NS (Statistics Canada, 2008a), a significant amount of M3P build up in soils may be attributed to grain corn production. Research has shown that compost has the ability to supply adequate amounts of P for high nutrient demanding crops such as corn and when matched with inorganic fertilizers, yields, equal to those of inorganic fertilizers only, can be expected (Mkhabela and Warman, 2005).

## 4.2 Materials and Methods

### 4.2.1 Experimental Design

This experiment (E2) was conducted over the 2008 and 2009 growing seasons and consisted of three trials (T1, T2 and T3). Experiment 2 aimed to evaluate yield effects and the overall P and N supply to grain corn throughout the first and second growing season following compost application. The trials were conducted within a 7.5 ha site in the Thomas brook watershed, Kings County, NS (45.08 $^{o}$ N, 64.75 $^{o}$ W) (Figure 4.1). Individual field plots were 6.1 m x 10 m in size running east to west, in an area of the field with uniform slope (Figure 4.2). The site is dominated by Pugwash series soil where soil is a sandy loam and over 20-80 cm deep with cemented layers (Holmstrom and Thompson, 1989). Trial 1 (T1) was conducted from May 14 – October 20, 2008. It involved a completely randomized block design with 16 plots that included three compost and an inorganic fertilizer treatments, each replicated four times (Figure 4.2). Trial 2 (T2), conducted from May 22 – October 22, 2009, included 20 additional plots in a completely randomized block design including three compost, an inorganic fertilizer and a control treatments (Figure 4.1). Trial 3 (T3) was conducted from May 22 – October 22, 2009 and involved monitoring the 16 former T1 plots over the second growing season to identify the residual effects of the various FYW compost and single inorganic fertilizer treatments.

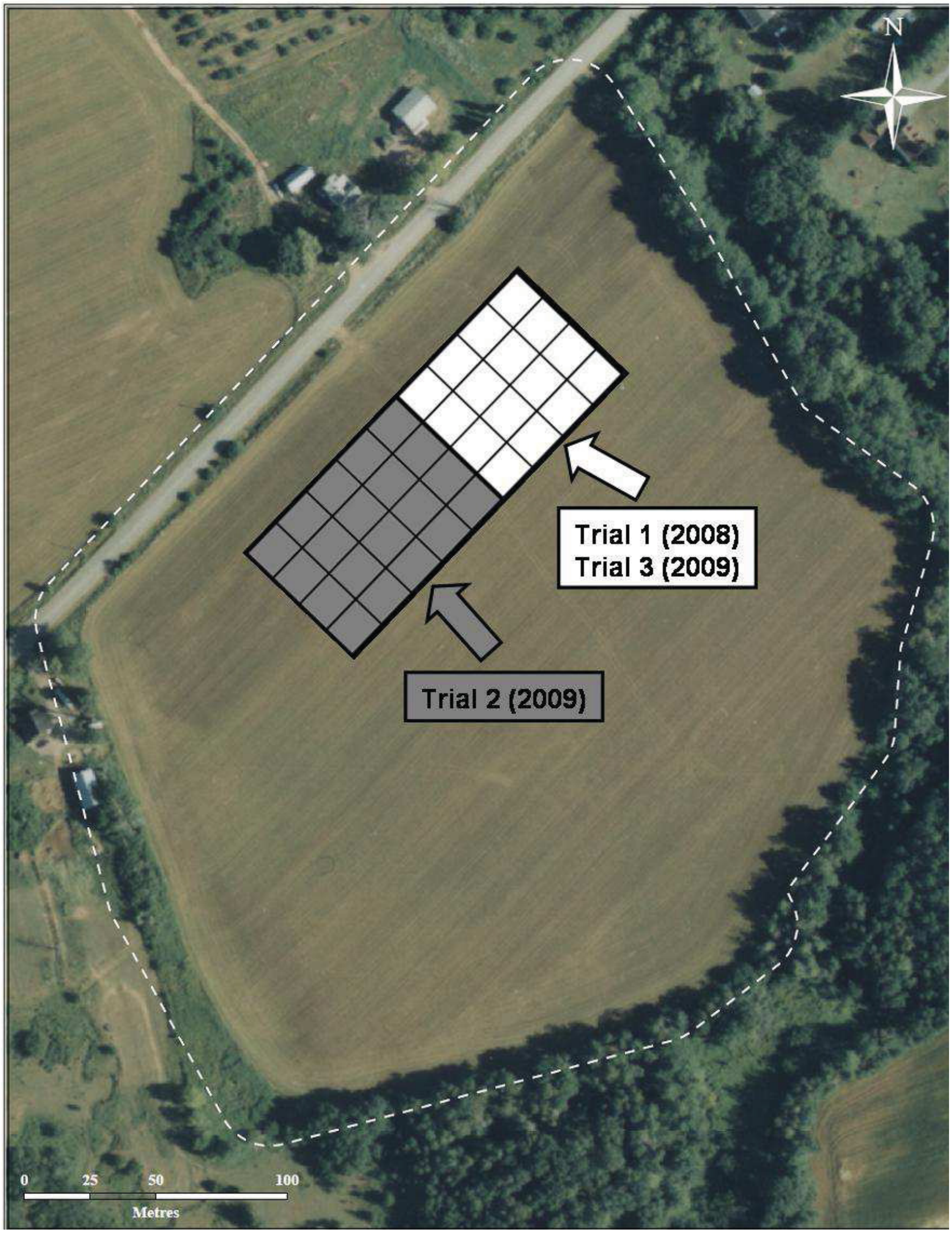

Figure 4.1 Site map of research area and locations of Trials 1, 2 and 3 in Experiment 2 (adapted from 2002 aerial photo from Department of Natural Resources for Agriculture and Agri-Food Canada).

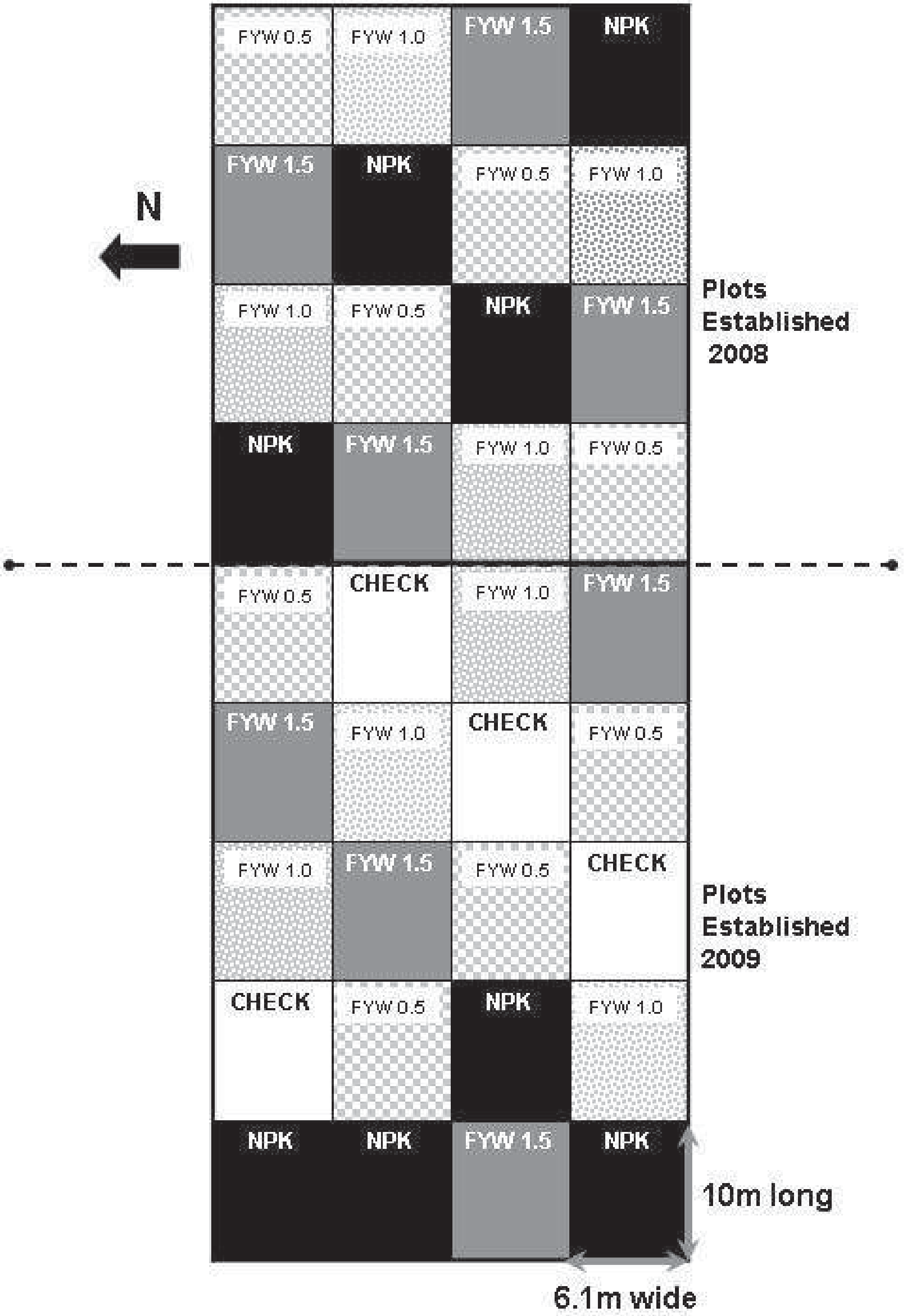

Figure 4.2 Schematic diagram of the experimental design for Experiment 2, including proximity of Trial 1 plots established in 2008 to Trial 2 plots established in 2009.

### 4.2.2 Site Description

The physical and chemical characteristics of the research area soil prior to treatment application in 2008 are summarized in Table 4.1. This field was in grass forage from 2002-2007. Grain corn *(Zea mays* L.*)* was grown in 2008 and 2009 with a glyphosate herbicide, Roundup®, applied once at weed emergence in both years. In both 2008 and 2009 the area of the field not included in the research plots received inorganic fertilizers at seeding and at the fifth leaf stage. There were no areas of the field that received manure applications in 2008 or 2009.

Table 4.1 Initial physical and chemical characteristics of research area soil as collected and analyzed prior to treatment application in May, 2008.

| **Texture** | **Coarse loamy till** |
|---|---|
| **% sand**** | **61** |
| **% silt**** | **31** |
| **% clay**** | **8** |
| **Bulk density (g cm$^{-3}$)*** | **1.28** |
| **Organic matter (%)*** | **3.21** |
| **pH*** | **6.25** |
| **$P_2O_5$ (kg ha$^{-1}$)*** | **220** |
| **$K_2O$ (kg ha$^{-1}$)*** | **190** |
| **Ca (kg ha$^{-1}$)*** | **2818** |
| **Fe (kg ha$^{-1}$)*** | **340** |
| **CEC (meq 100 g m$^{-1}$)*** | **12** |

* Values reported from laboratory soil analysis report
** Values taken from Holmstrom and Thompson (1989)

Dairy manure had been applied to the entire field with a Knight ® side slinging manure spreader in October 2007 at a rate of 32 t ha$^{-1}$ and was incorporated 2 weeks afterwards. Coefficient values necessary to calculating the nutrient supply were based upon a late fall application of semi-solid/liquid manure and no incorporation since the manure was incorporated two weeks following application (Burton *et al.*, 2003). The manure nutrient analysis, its dry matter content and application in the fall prior to spring planting were all taken into consideration when approximating the nutrient supply in 2008 and 2009. Based upon the above information and assumptions, dairy manure was assumed to have supplied approximately 22 kg ha$^{-1}$ N, 23 kg ha$^{-1}$ $P_2O_5$, and 89 kg ha$^{-1}$ $K_2O$ in 2008 and 4 kg ha$^{-1}$ N, 5 kg ha$^{-1}$ $P_2O_5$ and 8 kg ha$^{-1}$ $K_2O$ in 2009 (Burton *et al.*, 2003).

### 4.2.3 Compost Analysis

Three 1 kg composite (6-sub samples) compost samples were collected and analyzed in the spring of each year, prior to application. The elemental values, pH and dry matter were averaged and are provided in Table 4.2. The FYW compost utilized for T1 - T3 is a type of MSW compost being made up of FYW and, for both 2008 and 2009, originated from the same composting facility located in Kings County, NS. As shown in Table 4.2, variability exists between the FYW compost used in 2008 and that utilized in 2009. Raw materials, arriving to be composted at the Northridge Farm Composting facility, fluctuate; therefore, it is recommended to analyze compost for its chemical and physical composition prior to determining application rates.

Table 4.2 Analysis of food and yard waste (FYW) compost applied to treatment plots prior to treatment application in 2008 and 2009 including; carbon to nitrogen ratio, elemental values (%), pH and dry matter (%).

| | 2008 | 2009 |
|---|---|---|
| **C:N** | 10.2 | 7.88 |
| **pH** | 7.40 | 7.00 |
| **Dry matter (%)** | 48.7 | 54.0 |
| **N (%)** | 1.22 | 1.61 |
| **TP (%)** | 0.35 | 0.53 |
| **K (%)** | 0.31 | 0.14 |
| **$K_2O$ (%)** | 0.28 | 0.17 |
| **M3P (%)** | 0.72 | 1.22 |

### 4.2.4 Treatments

The treatments chosen were selected to enable an evaluation of incorporating compost into nutrient management practices and are described in Table 4.3.

Table 4.3 Application rates of food and yard waste (FYW) compost and inorganic fertilizer as applied to each treatment for Trial 1 in 2008 and Trial 2 in 2009.

| **2008 *** | **FYW compost** (kg ha$^{-1}$) | **Fertilizer N** (kg ha$^{-1}$) | **Fertilizer $P_2O_5$** (kg ha$^{-1}$) | **Fertilizer $K_2O$** (kg ha$^{-1}$) |
|---|---|---|---|---|
| **FYW1.5** | 36 000 | 65 | 22 | 0 |
| **FYW1.0** | 24 000 | 65 | 22 | 0 |
| **FYW0.5** | 12 000 | 65 | 22 | 0 |
| **NPK** | 0 | 96 | 32 | 31 |
| **Check** | 0 | 0 | 0 | 0 |
| **2009 **** | | | | |
| **FYW1.5** | 36 000 | 0 | 0 | 0 |
| **FYW1.0** | 24 000 | 0 | 0 | 0 |
| **FYW0.5** | 12 000 | 0 | 0 | 0 |
| **NPK** | 0 | 114 | 38 | 114 |
| **Check** | 0 | 0 | 0 | 0 |

* All plots had an estimated 22, 23, 89 kg ha$^{-1}$ of N-$P_2O_5$-$K_2O$ contributed from fall 2007 dairy manure application (Burton *et al.,* 2003).

** All plots had an estimated 4, 8, 5 kg ha$^{-1}$ of N-$P_2O_5$-$K_2O$ contributed from fall 2007 dairy manure application (Burton *et al.,* 2003)

In 2008, the treatments in T1 were: (i) FYW compost applied at 36 t ha$^{-1}$ and incorporated 3 days before planting with 217 kg ha$^{-1}$ of 30-10-0 fertilizer at planting referred to as FYW1.5; (ii) FYW compost applied at a rate of 24 t ha$^{-1}$ and incorporated 3 days before planting and 217 kg ha$^{-1}$ of 30-10-0 fertilizer at planting referred to as FYW1.0; (iii) FYW compost applied at 12 t ha$^{-1}$ and incorporated 3 days before planting and 217 kg ha$^{-1}$ of 30-10-0 fertilizer at planting referred to as FYW0.5; and (iv) inorganic fertilizer (30-10-0) at planting at a rate of 217 kg ha$^{-1}$ and (18-6-18) top dressed manually at the 5th leaf stage at a rate of 172 kg ha$^{-1}$ referred to as NPK (Table 4.3).

In 2009, the treatments in T2 were: (i) FYW compost applied at 36 t ha$^{-1}$ and incorporated 5 days before planting referred to as FYW1.5; (ii) FYW compost applied at a rate of 24 t ha$^{-1}$ and incorporated 5 days before planting referred to as FYW1.0; (iii) FYW compost applied at 12 t ha$^{-1}$ and incorporated 5 days before planting referred to as FYW0.5; and (iv) inorganic fertilizer (18-6-18) applied at planting at a rate of 250 kg ha$^{-1}$ and (18-6-18) top dressed at the 5th leaf stage manually at a rate of 385 kg ha$^{-1}$; and (v) a check treatment with no fertilizer or compost referred to as check (Table 4.3).

The FYW1.0 treatment rate, in both 2008 and 2009, was determined based upon nutrient requirements of grain corn, previous fall application of manure and assumptions made for available nutrients in source separated FYW compost (Canadian Fertilizer Institute, 2001) (Table 4.4). The laboratory incubation was conducted following the in-field experiments; therefore, accurate estimates of plant available nutrients from this FYW compost were not available when in-field compost application rates were projected. In the interest of determining a rate of FYW compost to meet nutrient requirements of grain corn without over- or under-applying nutrients, two other FYW compost rates were included in this experiment. FYW1.5 (36 t ha$^{-1}$) and FYW0.5 (12 t ha$^{-1}$) were aimed to supply 1.5 and 0.5 times the amount of N and P as supplied from the FYW1.0 (24 t ha$^{-1}$) treatment, respectively (Table 4.5). The sum of nutrients from all sources can be found in Table 4.5. The various rates of FYW compost were manually applied each year to plots prior to planting, on May 14, 2008 and May 22, 2009, utilizing the diagram found in Figure 4.2. For both T1 and T2, the compost was weighed in the field, applied manually to plots and subsequently incorporated by two passes with disk harrows. For T1, the inorganic fertilizer, 30-10-0, was banded on the subsurface soil at planting in the 8 row corn planter to all treatment plots and the top dress of inorganic fertilizer, 18-6-18, was broadcast manually at the 5th leaf stage to NPK treatment plots only. For T2, the inorganic fertilizer, 18-6-18, was banded manually directly following planting to NPK treatment plots only. A preliminary evaluation of the data from T1 in 2008 indicated the availability of nutrients were in excess of amounts required for grain corn growth and maturity; in part thought to be due to previous manure applications and inorganic fertilizer application at planting. Therefore, the FYW treatments in 2009 (T2) did not receive applications of inorganic fertilizers in order to better comprehend the available nutrients and soil properties solely associated with the FYW compost only. T3 did not involve applying any inorganic fertilizer, compost or manure in 2009, whereas T1 plots were exclusively monitored and sampled in 2009 to assess the residual effects of T1.

Table 4.4 Estimation of nutrients (kg ha$^{-1}$) applied as food and yard waste (FYW) compost to all FYW treatments in Trial 1 in 2008 and to both Trial 2 and Trial 3 in 2009.

| **Trial** | **Treatments** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **FYW0.5** | | | **FYW1.0** | | | **FYW1.5** | | |
| | **N** | **$P_2O_5$** | **$K_2O$** | **N** | **$P_2O_5$** | **$K_2O$** | **N** | **$P_2O_5$** | **$K_2O$** |
| **T1** | 15 | 13 | 13 | 29 | 26 | 27 | 44 | 39 | 40 |
| **T2** | 14 | 10 | 8 | 28 | 19 | 16 | 42 | 29 | 24 |
| **T3** | 15 | 13 | 13 | 29 | 26 | 27 | 44 | 39 | 40 |

Table 4.5 Sum of nutrients (kg ha$^{-1}$) from all sources including food and yard waste (FYW) compost, inorganic NPK fertilizer and previous manure applications to Trial 1 in 2008 and Trial 2 and Trial 3 in 2009.

| | **T1** (2008) | | | **T2** (2009) | | | **T3** (2009) | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ |
| **FYW0.5** | 102 | 58 | 102 | 18 | 18 | 13 | 19 | 21 | 18 |
| **FYW1.0** | 116 | 71 | 95 | 36 | 27 | 21 | 33 | 34 | 32 |
| **FYW1.5** | 131 | 84 | 134 | 46 | 37 | 29 | 48 | 47 | 45 |
| **NPK** | 118 | 55 | 120 | 118 | 46 | 119 | 4 | 8 | 5 |
| **Check** | | | | 4 | 8 | 5 | 4 | 8 | 5 |

### 4.2.5 Experimental Plots

Each experimental plot included 8 rows of corn, 75 cm apart, with the first and eighth row in each plot left as guard rows (Figure 4.3). Plant counts were recorded at emergence to establish germination rates and at harvest to determine stover and grain yield on a per area basis. In accordance with soil and tissue samples, weed and insect infestations were qualitatively monitored within plots throughout the growing season for the purpose of identifying pressure on growth of corn. The frequency and timing of tissue and soil samples for all three trials conducted in 2008 and 2009 are provided in Table 4.6. Air temperature and precipitation were monitored and recorded at the Agriculture and Agri-Food Canada Research Station in Kentville, NS for 2008 and 2009 (Environment Canada, 2010).

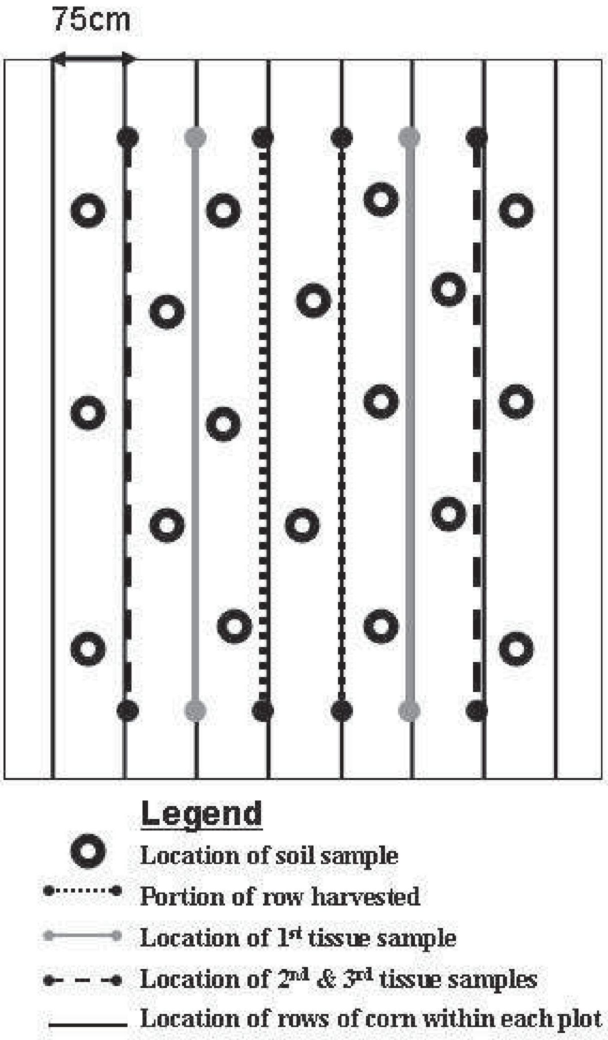

Figure 4.3 Single plot layout depicting the location and segment of corn rows used for collection of tissue, soil and harvest samples as collected over the 2008 and 2009 growing seasons.

Table 4.6 Frequency table including time of tissue and soil sample collection for Trial 1 in 2008 and Trial 2 and Trial 3 in 2009, where * indicates both a tissue and soil sample were collected.

| | May | | June | | July | | August | | October | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 08 | 09 | 08 | 09 | 08 | 09 | 08 | 09 | 08 | 09 |
| **Trial 1** | * | | * | | * | | * | | * | |
| **Trial 2** | | * | | * | | * | | | | * |
| **Trial 3** | | * | | * | | * | | | | * |

Prior to treatment application, six undisturbed soil cores were collected randomly from each plot to a depth of 15 cm, following a W pattern to ensure random sampling. Subsequently, 15 cm soil samples were collected between rows and adjacent to plants sampled in conjunction with tissue and yield samples. The first tissue and second soil samples were collected from the second and seventh rows, the second tissue and third soil samples and the third tissue and fourth soil samples were collected from third and sixth rows. At harvest the entire above ground portion of the corn plants were collected from fourth or fifth row, depending upon mechanical damage. Seasonal frequency, for both 2008 and 2009, of soil and tissue sampling can be found in Table 4.6.

### 4.2.6 Soils

For tilled soils, samples of the upper 0-15 cm can accurately estimate soil P available to surface runoff (Vadas *et al*., 2005). Soil samples were collected from T1 in 2008 and T2 and T3 in 2009 with a 30 cm soil T-shaped soil core sampler. One composite soil sample (six cores) was collected from the tilth layer (0-15cm) of each plot; prior to treatment application, at each tissue sample collection and following harvest (Table 4.4). All soil samples were air dried at 35$^o$C for 24 h and ground to pass through a 2 mm sieve, inductively coupled plasma spectrophotometer (ICAP) was used to quantify M3P (Dahlquist and Knoll, 1978), OM content of soils was determined by loss on ignition, and pH was determined using a pH meter (AOAC, 1990). These analyses were carried out at the Nova Scotia Department of Agriculture's Quality Evaluation Services Laboratory, Truro, Nova Scotia.

### 4.2.7 Tissues

Plant tissue sampling throughout the growing season and annual soil sampling have been suggested as an improved method of tracking crop nutrient levels at the most crucial growing stages to limit excessive nutrient application (Burton *et al*., 2003). Tissue samples were collected from T1 in 2008 and T2 and T3 in 2009 to estimate tissue N and P concentrations throughout the growing season (Figure 4.3). For each plot tissue samples were collected from (i) the entire above ground portion of 10 plants at the fifth leaf during the seedling stage, (ii) fully developed leaves (4) below the whorl each from 10 plants prior to tasseling and (iii) ear leaves (4) each from 10 plants between silk initiation and the brown silk stage (Thom *et al*., 2000). Samples were dried at 65$^{o}$C for 48 h and then grinded using an intermediate Micro Wiley Mill (AOAC, 1990; Method 950.02) with a 1 mm SS sieve. Tissue samples from 2008 and 2009 were analyzed for total N (TN) (AOAC, 1990; Method 990.03) and TP content (AOAC, 1990; Method 968.08). Total N or protein was determined on a LECO FP528 nitrogen analyzer (LECO Corporation, MI) the TP content was quantified using a radial model ICAP Varian 725 ES instrument (Dahlquist and Knoll, 1978). These analyses were carried out at the Department of Agriculture's Quality Evaluation Services Laboratory, Truro, Nova Scotia.

### 4.2.8 Harvest

Yields were determined from two rows; approximate 7.6 m strips were harvested from each plot on Oct 20, 2008 and Oct 22, 2009. Corn cobs were removed from the stalk, counted and subsequently shelled with the mechanical corn sheller. Total grain collected from each harvest row was weighed and recorded, and 500 g grain sub-samples were then dried for 48 h at 65˚C and analyzed for TN or protein (AOAC, 1990; Method 990.03) and TP content (AOAC, 1990; Method 968.08). The stover portion of each plant was cut 15 cm above the ground, weighed, dried at 65$^{o}$C for 48 h and ground using an intermediate Micro Wiley Mill (AOAC 1990; Method 950.02) with a 1mm SS sieve. In the case of both the grain and stover samples TN was determined utilizing a LECO FP528 N analyzer (LECO Corporation, MI), and the TP content was quantified using a radial model ICAP Varian 725 ES instrument. These analyses were carried out at the Nova Scotia Department of Agriculture's Quality Evaluation Services Laboratory, Truro, Nova Scotia. The TN or protein was converted to % N by Kjeldahl method.

### 4.2.9 Data Analysis

Response variables included corn grain yield (t ha$^{-1}$), N and P removed by grain (kg ha$^{-1}$), N and P uptake by stover (kg ha$^{-1}$), soil M3P (kg ha$^{-1}$), soil OM (%), soil CEC (meq 100 gm$^{-1}$), and soil pH. The grain yields for each plot in 2008 were the total weight of grain shelled from all cobs collected from two 7.6 m rows in each plot, as represented on a per hectare basis and corrected to 15.5% moisture (VanRoestel, 2009b). In 2009, considerable tractor damage inhibited collection of grain from two rows therefore grain yields were based upon the total weight of grain shelled from all cobs collected from one 7.6 m row in each plot, as represented on a per hectare basis and corrected to 15.5% moisture (VanRoestel, 2009b). Stover yield for each plot in 2008 was calculated based upon the total weight of stover as collected from two 7.6 m rows in each plot, and represented on a per area basis. Total N and P removed in grain for each plot were calculated as the grain yield multiplied by the associated N and P concentrations of the grain samples. Stover N and P removal was calculated as the stover yield multiplied by the N and P concentration found in the stover sample.

### 4.2.10 Statistical Analysis

In the 2008 monitoring year, three levels of compost and one level of fertilizer were established in a latinized arrangement across 4 field replicates. In the 2009 monitoring year, a check plot was added to the three levels of compost and one level of fertilizer and all were established in a latinized arrangement across 4 field replicates in another area of the field. Therefore, means were predicted for the average of 2008 and 2009 based upon 2009 check plot data and blocked by year.

The soil and tissue response variables collected were analyzed using repeated measures analysis of variance to determine seasonal means and linear and quadratic trends (Genstat, 2010). In order to compare the treatment effects, fourth order polynomial equations were used to fit curves to the soil and tissue data points and comparisons were made between the coefficients of these curves. Analysis of variance tables were constructed to identify grand means, standard error of the means (SEM) and F probabilities for all treatments in an effort to describe relationships between treatments. This form of statistical analysis was used to compare the variability between the treatment averages for all measured response variables. The variability was also examined graphically as presented throughout the results and discussions section within this thesis. To evaluate the difference across the treatments for yield, N and P concentration in grain and N and P removal in grain orthogonal contrasts were used. Comparisons were made between the check plot and plots that received any nutrient additions, fertilizer or compost, and linear or quadratic responses across compost application rates were identified. A contrast is an independent comparison; in this case between the check and the fertilizer and compost plots, an orthogonal contrast is used when there are at least three different treatments with which to compare. For plots seeded in the first year, response variables were collected for the second year to evaluate the residual effect of fertilizer and compost application rates. Orthogonal contrasts were used to evaluate differences across the treatment. All data was evaluated for normal distribution and large residuals were removed from the analysis. Data collected from the 2008 and 2009 application years were averaged together for the purpose of statistical analysis. Differences between the FYW compost and NPK fertilizer treatments applied in 2008 and 2009 did exist although for the purpose of improving the statistical strength of the analysis, data was averaged for the two years.

## 4.3 Results and Discussion

### 4.3.1 Immediate and Residual Effects of FYW Compost on Corn Grain

Data are reported graphically only when there were significant ($p<0.05$) treatment effects. There were no significant treatment effects to the response variable, corn grain N concentrations.

#### 4.3.1.1 Yield

To compare the overall treatment effect on corn grain yield the average of harvest yields (t ha$^{-1}$) from both 2008 and 2009 are provided in Table 4.7 and expressed on a

15.5% moisture basis. Results show that, statistically, both food and yard waste (FYW) compost treatments and the NPK fertilizer treatment yielded significantly more corn grain than check plots ($p=0.004$) (Figure 4.4). Mamo *et al.* (1998) also found that municipal solid waste (MSW) compost, with or without additional N fertilizer, increased corn grain yields when compared to no compost. Ozores-Hampton *et al.* (2000) found that in the first and second year following MSW compost application both marketable snap bean yields and yields per plant were higher in comparison to unfertilized plots. In the present study, results also showed that the NPK granular fertilizer treatment yielded significantly more corn grain than the FYW compost treatments ($p<0.001$) (Table 4.8). Contrasting yields between NPK fertilizer and FYW compost treatments can be found in Table 5.7. Mkhabela and Warman (2005) found MSW compost treatments produced lower grain yields than that of an NPK treatment, but higher total dry matter yields were found with MSW compost matched with an NPK fertilizer. Sullivan *et al.* (2002) also found that compost plus N fertilizer produced yields greater than those from N fertilizer only or compost only. In 2008, the FYW treatments also received NP fertilizers that supplied an additional 65 kg N $ha^{-1}$ and yields were 93-97% of the 2008 NPK treatment yields. In 2009, the FYW treatments were not supplemented with NPK fertilizers and only yielded 59-76% of the 2009 NPK treatment grain yields. Results from E1 indicate that FYW compost does not contribute sufficient amounts of plant available N for corn growth in the first 3 months following application. Hargreaves *et al.* (2009) also concluded MSW compost to not provide sufficient N to plants and that yields were lower than expected. FYW compost applications supplemented with an inorganic N fertilizer may reduce yield difference between FYW compost and NPK treatments.

Table 4.7 Grain corn harvest yield (t ha$^{-1}$), N and P concentration (%) and total P (TP) and total N (TN) (kg ha$^{-1}$) removed in corn grain following food and yard waste (FYW) compost, NPK treatment applications in 2008 and 2009 and check plots in 2009.

| Treatment | Year | Yield (t ha$^{-1}$) | N (%) | P (%) | P removed (kg ha$^{-1}$) | N removed (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|
| **Check** | 09 | 3.23 | 1.30 | 0.38 | 12.30 | 41.44 |
| **FYW0.5** | 08 | 8.95 | 1.85 | 0.30 | 27.10 | 164.97 |
| | 09 | 3.06 | 1.31 | 0.38 | 11.52 | 39.49 |
| **FYW1.0** | 08 | 9.25 | 1.88 | 0.30 | 28.15 | 173.41 |
| | 09 | 3.56 | 1.32 | 0.37 | 13.16 | 46.37 |
| **FYW1.5** | 08 | 8.95 | 1.90 | 0.30 | 26.85 | 169.47 |
| | 09 | 3.93 | 1.28 | 0.38 | 14.94 | 49.89 |
| **NPK** | 08 | 9.58 | 1.89 | 0.29 | 28.03 | 180.39 |
| | 09 | 5.19 | 1.30 | 0.34 | 17.56 | 68.33 |

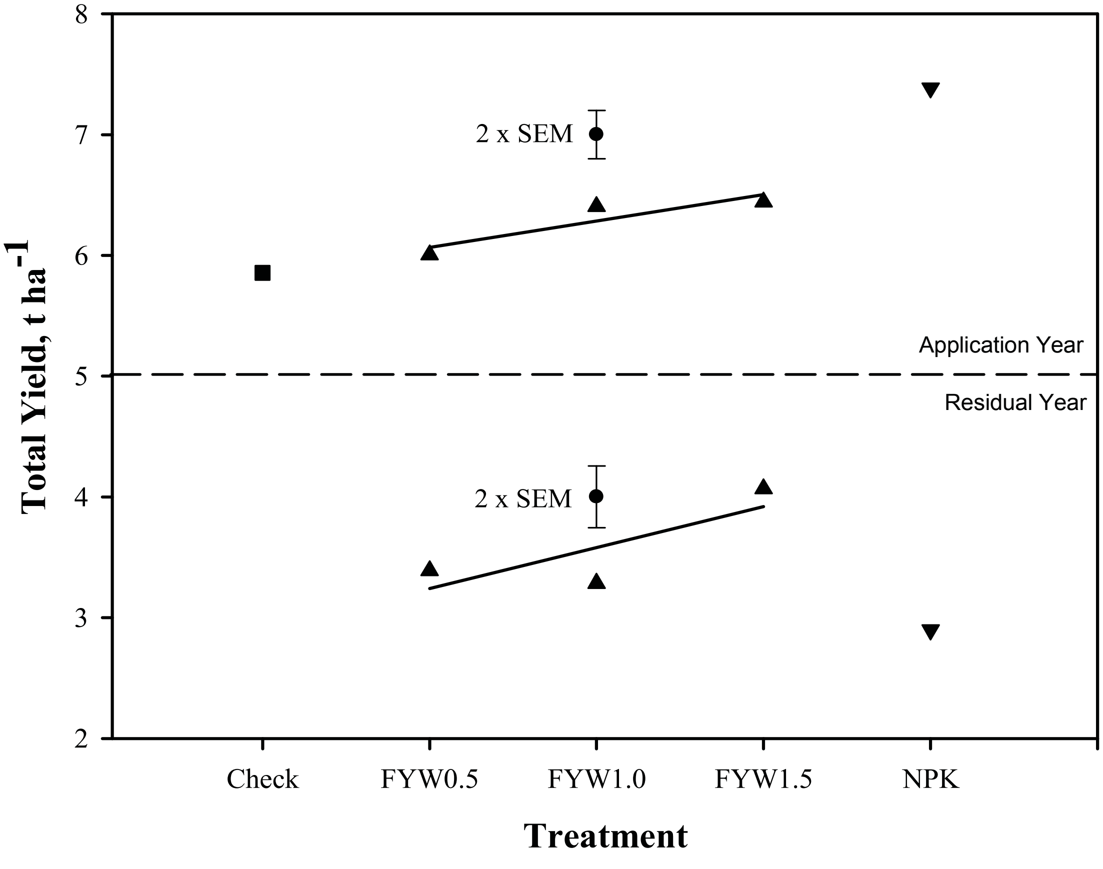

Figure 4.4 Linear trends in corn grain yields (t ha$^{-1}$) following application of food and yard waste (FYW) compost treatment rates and corn grain yields following NPK treatment and check shown separately for the 2009 residual year and the combined average of 2008 and 2009 application years data.

Table 4.8 Significant relationships identified through an ANOVA between corn response variables and treatments as identified for the year of application and for the residual year, represented by p-values $< 0.05$ (blank spaces indicate p-values between 0.05 - 0.1).

| | **Check vs. FYW and NPK** | **NPK vs. FYW** | **Linear Compost** |
|---|---|---|---|
| Response variable | Application year | | |
| **Yield** | **$p = 0.004$** | **$p < 0.001$** | |
| **P removed by Grain** | **$p = 0.021$** | **$p = 0.006$** | |
| **N removed by Grain** | **$p = 0.007$** | **$p < 0.001$** | |
| **Grain % P** | **$p = 0.033$** | **$p < 0.001$** | |
| Response variable | Residual year | | |
| **Yield** | | **$p = 0.046$** | **$p = 0.043$** |
| **P removed by Grain** | | **$p = 0.026$** | |
| **N removed by grain** | | **$p = 0.025$** | |

On average for the 2008 and 2009 application years growing season, treatment FYW1.5 yielded a significantly greater amount of corn grain than FYW0.5 (2xSEM=0.3986), although the linear response to FYW compost application rate was not significant across all rates (Figure 4.4). This finding indicates that increasing application rates from 12 - 36 t ha$^{-1}$ of FYW compost can result in significantly higher grain yields. Findings from the incubation experiment, E1, indicate that the plant available N supply by FYW compost increased with increasing application rates but this trend was not found to be significant. The added supply of plant available N by the FYW1.5 compost rate could have contributed to these increased yields. Notably, the FYW1.5 compost treatment, which had received the highest rate of 36 t ha$^{-1}$ of FYW compost, yielded less grain than the NPK treatment. The FYW1.0 compost treatment rate was calculated to supply grain corn with amounts of plant available N and P sufficient for its uptake and removal requirements (Canadian Fertilizer Institute, 2001) and equal to amounts applied with the NPK treatment. Although, the N mineralization findings from E1 reveal that assumptions for the plant available N supply by FYW compost for in-field experiments were greatly over estimated. Based upon the results from E1, in order to adequately supply sufficient plant available N to a grain corn crop, 205kg/ha, an application rate of approximately 6000 t ha$^{-1}$ FYW compost would have needed to be applied to the soil (Canadian Fertilizer Institute, 2001). The greatest application rate of FYW compost used for in this study was 36 t ha$^{-1}$ (FYW1.5), supplying substantially less plant available N then required by the grain corn crop therefore also explaining the difference between the FYW1.0 and the NPK treatment yields.

The results from the in-field experiment T2, identified that the 2008 FYW compost treatment applications resulted in higher grain yields than when compared to the respective treatments in 2009 (Table 4.7). The difference between 2008 and 2009 yields may be due to the lack of N fertilizers accompanying those 2009 FYW compost applications. Also, in 2008 bumper crops of silage, high moisture and dry grain corn were reported throughout the Annapolis Valley, NS as a result of earlier planting dates and above average corn heat units (CHU) and moisture (VanRoestel, 2008). Notably, 2009 corn yields in the Annapolis Valley, NS were impacted by weather conditions such as less sunshine hours and heat in July and September compounded by excessive rain in August (VanRoestel, 2009a). Table 5.9 highlights the climatological conditions near the research site in 2008 and 2009. Weather conditions not only affect the growth and development of a crop such as grain corn but also have an effect on the mineralization of N from an organic source, in the soil. Eghball *et al.* (2004) investigated the residual effects of composted manure on corn and soil properties and reported that nitrate concentrations and quantities were similar for all treatments in their best corn producing year but were much greater for fertilizer than compost treatments in the drier years. A four year study on corn production affected by tillage and starter fertilizer reported similarly that cool and wet conditions reduced plant height in comparison to other years (Vetsch and Randall, 2002). The variation between the 2008 and 2009 growing seasons for this specific research may be due to lack of N fertilizers applied with the FYW compost to treatments and the difference between growing seasons in terms of accumulated CHUs and precipitation.

Table 4.9 Mean air temperature ($^{o}$C), corn heat units (CHU) and total rainfall (mm) for 2008 and 2009 growing seasons (May 1 – September 30), (Environment Canada, 2010).

| | **2008** | | | **2009** | | |
|---|---|---|---|---|---|---|
| **Month** | **Corn Heat Units** | **Rainfall (mm)** | **Mean Temperature ($^{o}$C)** | **Corn Heat Units** | **Rainfall (mm)** | **Mean Temperature ($^{o}$C)** |
| May | 306 | 94 | 10.8 | 373 | 58 | 12.4 |
| June | 611 | 42 | 17.0 | 591 | 62 | 16.6 |
| July | 810 | 49 | 21.5 | 733 | 112 | 19.1 |
| August | 721 | 121 | 18.8 | 750 | 178 | 20.1 |
| September | 506 | 116 | 14.7 | 476 | 67 | 14.2 |
| **Total** | **2954** | **422** | **16.6 (mean)** | **2923** | **477** | **16.5 (mean)** |

The analysis of variance indicated that each of the previously applied FYW treatments yielded significantly higher yields than the previously applied NPK treatment (p=0.046) (Table 4.8). The NPK granular fertilizer is considered to be readily plant available whereas the FYW compost utilized was an organic source of nutrients which slowly releases plant available nutrients (Sullivan *et al.,* 2002). The results from E1 show that, following the incorporation of FYW compost, mineral N increased over the entire 88 d incubation at amounts greater than soil only (p<0.001) with a trend for continued mineralization past the 88 days. In 2009, the previously applied compost treatments yielded similarly (92-111%) to the present years applications and exceeded (102-126%)

yields from unamended check plots (Tables 4.7 and 4.10). Ozores-Hampton *et al.* (1994) planted squash in plots where MSW compost had previously been applied and obtained yields 23% higher than the control. Their study concluded that amending soils with MSW can increase the growth and yield of squash in the second year following application (Ozores-Hampton *et al*., 1994). Eghball *et al.* (2004) concluded that in the second year following composted beef manure application, corn grain yields were greater than those from check plots. Furthermore, applications of food waste compost to tall fescue grass showed a significant increase in grass yield in the second and third season following compost application (Sullivan *et al.,* 2002). Mamo *et al.* (1998) reported similar findings, whereby the residual effects of MSW compost yielded greater than or equal to corn grain yields of control plots. Results from the incubation study, E1, indicate a trend for FYW compost to deliver plant available nutrients in the second growing season following application. The residual effects of FYW compost application on corn grain identifies a linear trend between compost application rate and yield, although this was not a significant trend across all treatment rates (2xSEM=0.5118) (Figure 4.4). FYW compost can be expected to contribute plant available N in the second year following application, latter plant available N contributions could be quantified with longer-term incubation experiments.

Table 4.10 Comparison of means to identify the residual effect of food and yard waste (FYW) compost and NPK treatment applications in 2009 on corn grain yield (t $ha^{-1}$), N and P grain concentrations (%) and N and P removed (kg $ha^{-1}$) or N and P concentrations x yield (means highlighted in bold are significantly different than the NPK treatment, based upon 2 x SEM).

| | **Yield (t $ha^{-1}$)** | **N (%)** | **P (%)** | **N removed (kg $ha^{-1}$)** | **P removed (kg $ha^{-1}$)** |
|---|---|---|---|---|---|
| **FYW0.5** | 3.39 | 1.25 | 0.360 | **42.28** | 12.18 |
| **FYW1.0** | 3.28 | 1.25 | **0.380** | 40.94 | **12.48** |
| **FYW1.5** | **4.07** | 1.24 | **0.373** | **51.03** | **15.12** |
| **NPK** | 2.90 | 1.24 | 0.365 | 35.76 | 10.53 |
| **SEM** | 0.2559 | 0.0264 | 0.0068 | 2.904 | 0.8854 |

In summary, when weather conditions favour N mineralization and inorganic fertilizers are incorporated to supply additional N to meet crop requirements, corn grain yields from FYW compost can be expected to be similar to those from inorganic fertilizers only. Findings from the present study also identify that the effects on yield of a broadcast, spring FYW compost application can last for at least two growing seasons, but further investigation is needed to quantify the supply of nutrients in the second year following FYW compost application.

#### 4.3.1.2 Phosphorus Removed by Corn Grain

The concentration of P in and amounts of P removed by corn grain as measured at harvest following FYW and NPK treatment application in both 2008 and 2009 are provided in Table 4.7. The grain harvested from the FYW treatment plots contained significantly higher concentrations of P than the grain from the NPK treatment plots ($p<0.001$) as shown in Figure 4.5. The addition of OM, such as FYW compost, to soil increases soil fertility, thereby increasing the nutrients available for plant uptake (Singer *et al.,* 2004). Results from E1 suggest a slow release of plant available P from the FYW compost, unlike inorganic fertilizers. A slower nutrient release from the FYW compost as compared to NPK fertilizers may have resulted in later season availability of P. Phosphorus transfer to the grain portion of the plant occurs later in the season which would coincide with nutrient release from the FYW compost. The in-field results show that the rate of FYW compost application did not significantly affect the corn grains P concentration (2xSEM=0.005) (Figure 4.5). Similarly, Eghball and Power (1999) found no significant difference in corn grain P concentrations between all their various compost treatment application rates. Corn grain harvested from the check plots, in the present study, contained significantly higher concentrations of P than the NPK treatments (p=0.033) (Figure 4.5). No compost or fertilizer was applied to check plots; therefore, higher P concentrations in the grain harvested from check plots may be due to differences in soil test P between plots. Prior to compost and/or fertilizer application in 2008 the M3P soil test results ranged from 146-300 kg ha$^{-1}$ with an average of 219 kg ha$^{-1}$ and prior to amendment application in 2009 the M3P soil test results ranged from 182-374 kg ha$^{-1}$ with an average of 269 kg ha$^{-1}$. Food and yard waste compost has the ability to supply sufficient P to corn and yield variability may be reduced with supplemental N additions.

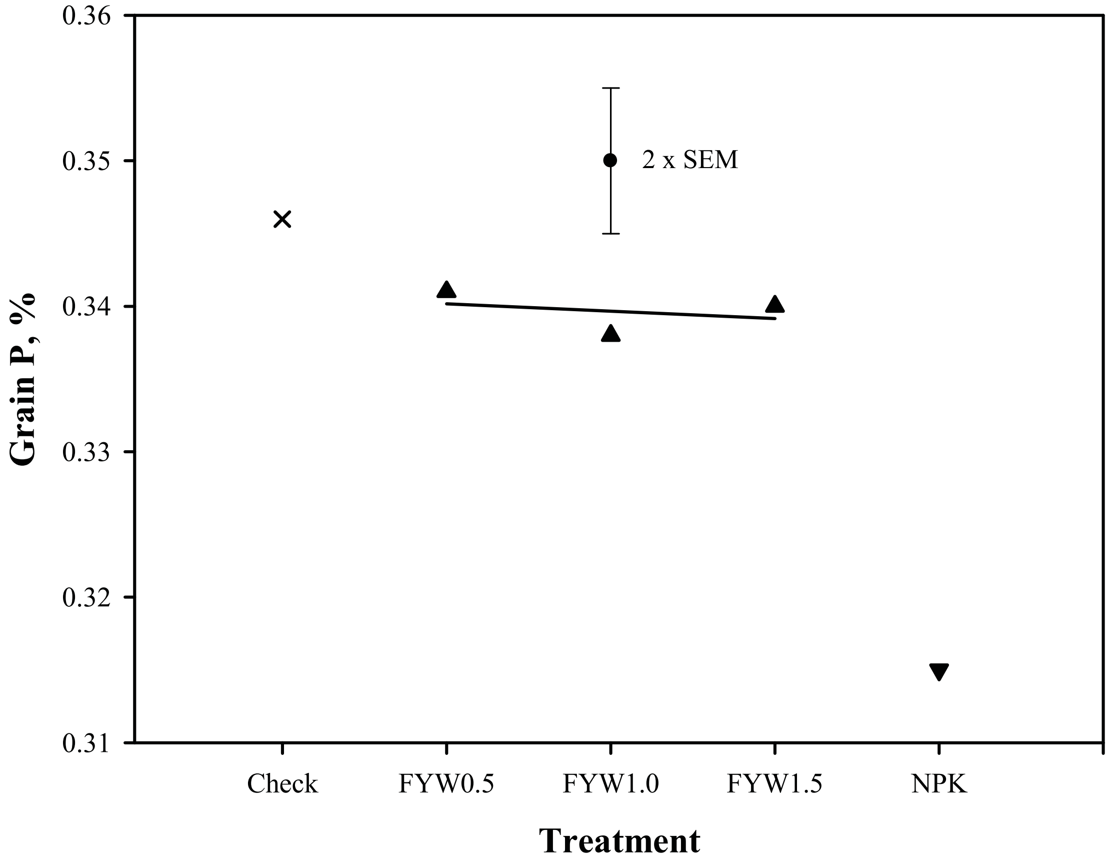

Figure 4.5 The combined averages of 2008 and 2009 application years corn grain P concentrations (%) following application of food and yard waste (FYW) compost treatment rates, NPK treatment and check.

On average, FYW and NPK treatments resulted in more P removed by grain than check plots (p=0.021) with NPK fertilizer treatments resulting in greater removal of P by the corn grain than the FYW treatments (p=0.006) (Table 4.8) (Figure 4.6). Considerably lower concentrations of P were measured in the grain harvested from the NPK treatment plots but because removal is based upon yield the NPK treatment resulted in significantly higher TP removed. McCoy *et al.* (1986) concluded that TP uptake increased significantly in response to P application, when the source of P was readily available. Eghball and Power (1999) found that P uptake by corn following compost application was greater than or similar to their fertilizer treatment, as a result of correct N and P availability assumptions from compost. Results from E1 suggest a supply of plant available P later in the season and that amounts of P delivered from the FYW1.5 treatment would be sufficient for crop growth. Although the results from E1 also suggest FYW compost does not supply sufficient amounts of N, which would affect crop growth and, ultimately, harvestable grain yields. Results from both experiments suggest that if FYW compost applications were paired with inorganic N fertilizers, yields and P removal would be higher.

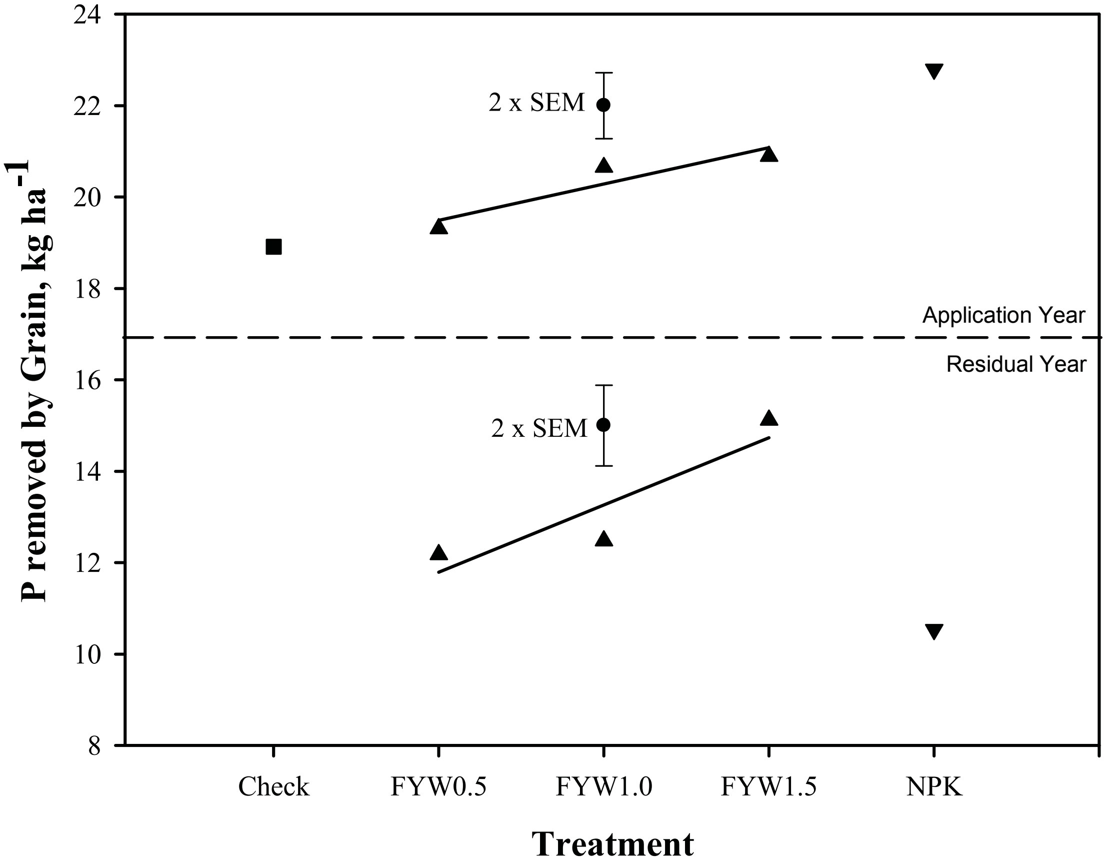

Figure 4.6 P removed by grain (kg ha$^{-1}$) following application of food and yard waste (FYW) compost treatment rates and P removed following NPK treatment and check shown separately for the 2009 residual year and the combined average of 2008 and 2009 application years data.

On average, for the 2008 and 2009 application year growing seasons, an increase in the FYW compost application rate did not result in statistically significant increases in P removal in the grain (2xSEM=1.44) (Figure 4.6). Multiple years of data and additional repetitions may reduce this SEM and produce a significant linear relationship between P removed in grain and the compost application rate. A non significant linear trend does exist between P removed and the FYW compost rates, similar to the yield results. The amount of P removed by corn is relative to its yield, on average grain yields from FYW compost treatment plots suffered from a lack of plant available N. Similar to previous recommendations, pairing FYW compost with N inorganic fertilizers has the potential to increase yield and further extinguish the effects of varying compost application rates on yield and nutrient removal.

Previous applications of FYW compost resulted in significantly greater amounts of P removed by the grain corn in the second growing season than compared to previous NPK fertilizer applications (p=0.026) (Table 4.8). A positive, significant, linear relationship existed between the compost application rate and the amount of P removed by grain in the residual year (p=0.043) (Table 4.8). Results from E1 indicate that both plant available P concentrations and release per tonne of compost increased with increasing application rates. Amounts of P removed in the residual year by corn grown in FYW compost treatment plots were not as high as those from the application year but they were higher than second year NPK treatment plots; thereby indicating a residual supply of plant available nutrients. This finding suggests that reduced application rates of FYW compost in the second growing season paired with inorganic N fertilizers may be sufficient to meet a grain corn crop's nutrient requirements. The second year supply of plant available N and P from FYW compost needs to be determined to further quantify appropriate second year application rates. FYW compost with additional inorganic N fertilizers has the potential for greater removal of P in grain corn, when greater yields are achieved, in comparison to solely applying inorganic fertilizers.

#### 4.3.1.3 Nitrogen Removed by Corn Grain

To compare the overall effect of the FYW compost and NPK treatments on N concentrations in corn grain and on the total N removed by corn grain, the average of both treatment application years are provided in Table 4.7. Corn grain N concentrations were not significantly influenced by any of the treatments evaluated within this experiment in either 2008, the application year, or 2009, the residual year.

The NPK fertilizer treatment resulted in greater N removal by corn grain than from FYW compost treatments ($p<0.001$) and both removed more than the unamended check ($p=0.007$) (Table 4.8) (Figure 4.7). Quantities of N removed in the corn grain for all treatments were in the range of the general estimates of amounts necessary for grain corn yields equivalent to 9.4 t ha$^{-1}$ (VanRoestel, 2009b). These general estimates are based upon typical nutrient concentrations and yields for good growing conditions in eastern Canada and as such will vary by crop yield and variety, soil fertility and from year to year (Canadian Fertilizer Institute, 2001). Eghball and Power (1999) demonstrated that when compost treatment applications were based upon accurate estimates of nutrient availability, the N removed by the grain was similar for compost and fertilizer treatments. This present study identified that the FYW compost supplied substantially less N (0.33–1.24 kg N ha$^{-1}$) than was estimated (14 – 44 kg N ha$^{-1}$) when applications were made in 2008 and 2009. Also, check plots were not supplied with any source of N or P. This in-field research suggests that the availability of N from this research area soil was significantly greater than hypothesized. This may be due to the ploughing under of the previous forage crop in 2007 and its subsequent N contribution.

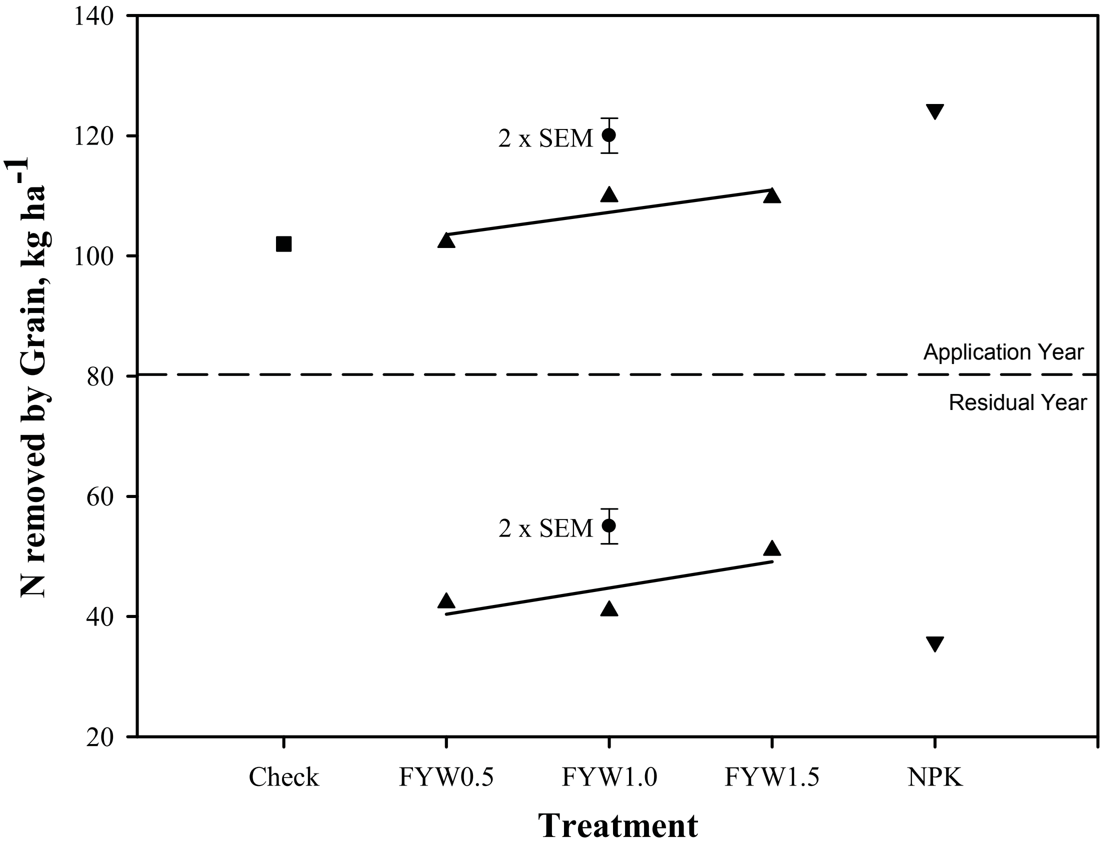

Figure 4.7 N removed by grain (kg ha$^{-1}$) following application of food and yard waste (FYW) compost treatment rates and N removed in corn grain following NPK treatment and check shown separately for the 2009 residual year averages and the combined average of 2008 and 2009 application years data.

A study on the effects of food waste compost on available soil N and grass yields found that compost did not affect N uptake or grass yields in year one but that yields increased in the second and third seasons after application (Sullivan *et al.,* 2002). Residual effects, such as an increase in soil N, P and OM, following compost application can last for several years because only a fraction of the N and other nutrients in compost become plant available in the first year of application (Eghball *et al.*, 2004). The analysis of variance indicated that the residual effects of the FYW compost application resulted in significantly more N removed in the grain than the residual NPK treatment (p=0.025) (Table 4.8). Rodd *et al.* (2000) found that total uptake of N by annual ryegrass was unaffected by previous fertilizer addition, irrespective of application rate. The results from this study indicated that MSW compost amended plots had higher residual availability of N and the total uptake of N by ryegrass was greater than manure amended plots (Rodd *et al.,* 2000). Notably, this source-separated MSW compost exhibited a similar pH and % dry matter with both a lower percentage of N and P than the presently researched FYW compost and still remained superior to manure and fertilizer in terms of residual N contributions (Rodd *et al.,* 2000). Eghball *et al.* (2004) investigated the residual effects of composted manure applications on corn production and soil properties utilizing compost that more closely reflected the composition of the FYW compost used in the present research in terms of pH and N, P and C content. This study concluded that N uptake by grain in residual compost plots was greater than unfertilized check plots and that N mineralization in the second year following application contributed plant available N thereby causing an increase in N removal by grain (Eghball *et al.,* 2004).

Greater N removal by corn following previous applications of FYW compost, found in the present study, indicates residual N is released from the compost over the second growing season. Sullivan *et al.* (2002) established that previous applications of food waste compost reduced the compost N requirement by 3.6 – 5.2 % in the second year after application. Findings from E1 identify that only 0.09 - 0.11% of the total N applied from the FYW compost is plant available over the first growing season following application. As the rate of previously applied FYW compost increased, the N removal by corn also increased although not significantly, similarly to the % N in grain and the grain yields (Table 4.10). The results from N removal in the second year following application, along with findings from E1, indicate that significant amounts of mineral N may be available in the following year from FYW compost application. Residual N contributions need to be further quantified to determine the reduction in the requirement for additional fertilizer N or compost N in subsequent growing seasons.

### 4.3.2 Immediate and Residual Effects of FYW Compost on Tissue and Stover

Data are reported graphically only when there were significant ($p<0.05$) treatment effects. There were no significant treatment effects to the response variable, corn stover N concentrations.

#### 4.3.2.1. Tissue Phosphorus

The effects of the FYW and NPK treatments on P **c**oncentrations in corn plant tissue samples, collected throughout the growing season and at harvest for both 2008 and 2009, are averaged and provided in Table 4.11.

Table 4.11 P concentrations (%) in corn tissue samples collected in June, July and October following, and averaged for, food and yard waste (FYW) compost and NPK treatment applications in 2008 and 2009 and for the second (residual) growing season following treatment application, 2009.

| | **P Concentrations (%)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Application Year** | | | | **Residual Year** | | | |
| | **June** | **July** | **Oct.** | **Mean** | **June** | **July** | **Oct.** | **Mean** |
| **FYW0.5** | 0.46 | 0.25 | 0.23 | **0.31** | 0.46 | 0.30 | 0.18 | **0.31** |
| **FYW1.0** | 0.45 | 0.24 | 0.23 | **0.31** | 0.46 | 0.31 | 0.20 | **0.32** |
| **FYW1.5** | 0.44 | 0.30 | 0.23 | **0.32** | 0.47 | 0.31 | 0.18 | **0.32** |
| **NPK** | 0.45 | 0.23 | 0.21 | **0.30** | 0.44 | 0.34 | 0.10 | **0.29** |
| **Check** | N/A | | | | 0.47 | 0.30 | 0.18 | **0.31** |

All treatments exhibited the highest P concentrations at the beginning of the season when demand for nutrients is high, followed by a decrease from the seedling stage to prior to tasseling with a further reduction in tissue P measured in the stover at harvest (Figure 4.8). High P concentration in corn plant tissue in its early vegetative stages reflects amounts of P required for early plant growth and root development and is greater than in the later vegetative stages (McWilliams *et al.,* 1999). Sneller and Laboski (2009) also demonstrated an early season crop response to P applications identified by significant increases in P uptake in the early vegetative stage that increased with increasing P application rate.

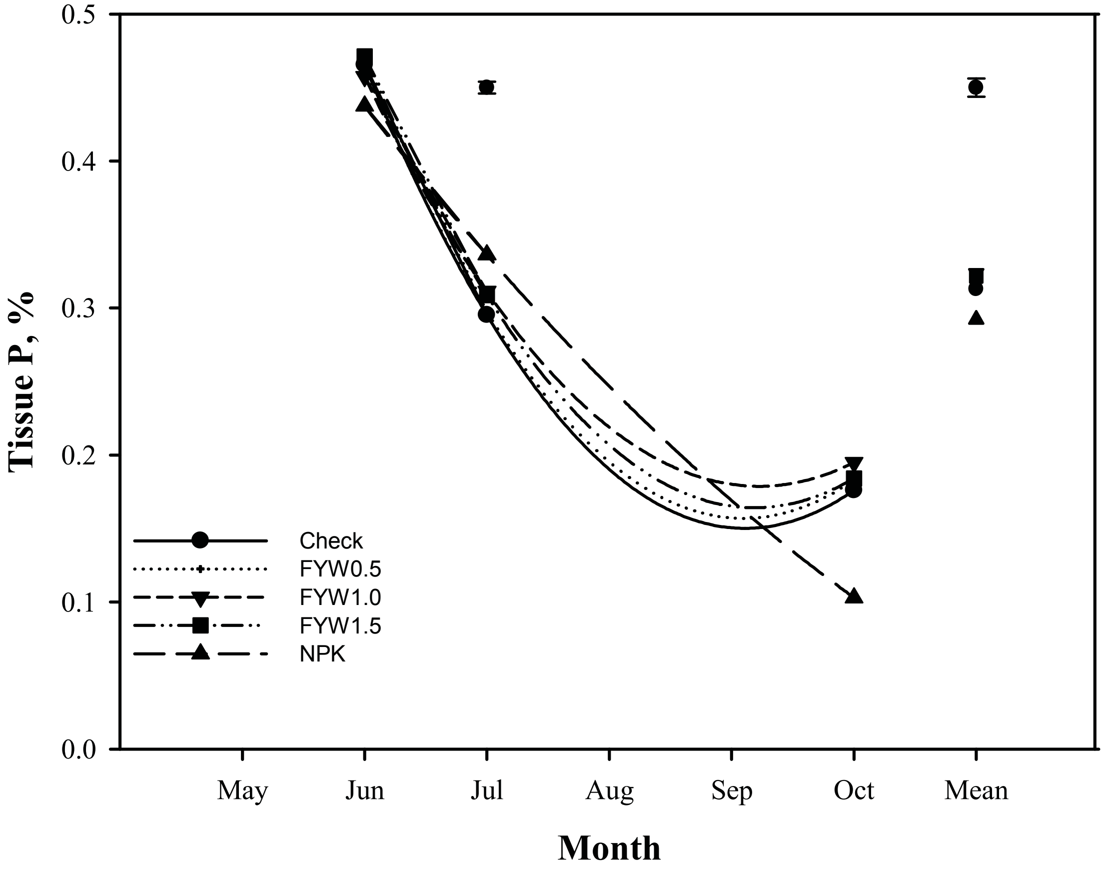

Figure 4.8 The combined average of 2008 and 2009 application years plant tissue P concentrations (%) following food and yard waste (FYW) compost treatments, NPK treatment and check.

On average for the season, FYW compost application resulted in corn tissue samples that, statistically, had significantly higher P concentrations than NPK fertilizer application ($p<0.001$) (Table 4.12). As shown in section 4.3.3.1 of this Chapter, FYW compost treatments also resulted in higher seasonal averages of soil M3P then when compared to the NPK treatment. These results indicate that the 12 – 36 t ha$^{-1}$ of FYW compost applied to treatment plots prior to planting contributed significantly greater amounts of plant available P then the NPK fertilizer only. Also results from E1 show that treatments FYW1.0 and FYW1.5, statistically, provided significantly greater amounts of plant available P than a soil only control, at the time of incorporation.

Table 4.12 Significant relationships identified between corn response variables and treatments as identified for the year of application and for the residual year, represented by p-values $< 0.05$ (blank spaces indicate p-values between 0.05 - 0.1).

| | **Check vs NPK & FYW** | **NPK vs. FYW** | **Linear Compost** |
|---|---|---|---|
| Response variable | Application year | | |
| **Tissue % P** | | **$p < 0.001$ (mean)**<br>**$p < 0.001$ (line)** | |
| **Tissue % N** | **$p < 0.001$** | **$p < 0.001$ (mean)** | |
| **Stover % P** | | **$p < 0.001$** | |

Statistically, P concentrations measured in plant tissue samples were, on average, higher throughout the season following FYW compost supplications than NPK fertilizer ($p<0.001$) (Table 4.12). The NPK treatment exhibited lower concentrations of P in tissue samples at the beginning of the season, higher in the samples collected in July and lower again at harvest in the stover samples, in comparison to the FYW treatments. Notably, the average concentration of P in the tissue samples collected from the NPK plots in July was statistically higher than the average concentrations measured in FYW and check plots, unlike the seasonal trend. Tissue sample collection in July closely followed the top dress of inorganic NPK fertilizer that was only applied to NPK plots. Results from E1 show that the FYW compost steadily released plant available P over the 88 d incubation whereas NPK inorganic fertilizers provide readily available plant nutrients. Also, as shown in section 4.3.1.2 of this Chapter, FYW compost also resulted in higher concentrations of P in the grain portion of the corn. Thus the FYW compost applied gave a slower release of nutrients over the growing season than NPK fertilizers; therefore, providing the nutrients needed by the crop later in the season for maturing processes and accounts for the higher grain and stover concentrations at harvest.

The concentration of P measured in tissue samples collected throughout the second (residual) growing season and at harvest following treatment application, 2009, are provided in Table 4.11. There were no significant treatment effects on P concentrations in tissue samples collected over the second (residual) growing season.

#### 4.3.2.2 Tissue Nitrogen

The concentration of N in tissue samples, as measured throughout the growing season and at harvest, following FYW and NPK treatment application in both 2008 and 2009 are provided in Table 4.13.

Table 4.13 N concentrations (%) in corn tissue samples collected in June, July and October following, and averaged for, food and yard waste (FYW) compost and NPK treatment applications in 2008 and 2009 and for the second (residual) growing season following treatment application, 2009.

| | **N Concentrations (%)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Application Year** | | | | **Residual Year** | | | |
| | **June** | **July** | **Oct.** | **Mean** | **June** | **July** | **Oct.** | **Mean** |
| **FYW0.5** | 5.16 | 2.03 | 0.89 | **2.62** | 5.37 | 3.05 | 0.94 | **3.12** |
| **FYW1.0** | 5.13 | 2.02 | 0.88 | **2.68** | 5.32 | 3.08 | 0.93 | **3.11** |
| **FYW1.5** | 5.23 | 1.97 | 0.86 | **2.69** | 5.42 | 3.03 | 1.01 | **3.15** |
| **NPK** | 5.22 | 1.95 | 0.88 | **2.68** | 5.33 | 3.65 | 0.93 | **3.33** |
| **Check** | N/A | | | | 5.56 | 2.82 | 0.96 | **3.12** |

All treatments resulted in tissue samples with concentrations of N highest at the beginning of the season when demand for nutrients is high, followed by a decrease from the seedling stage to prior to tasseling with a further reduction in tissue N measured in the stover at harvest (Figure 4.9). The lowest concentrations at harvest were expected due to the N and P transfer to and use by the grain portion of the plant. Results show that the NPK fertilizer treatment resulted in tissue samples with a, statistically, significantly higher seasonal average of N concentrations than FYW treatments and check ($p<0.001$) (Table 4.12). Hussaini *et al.* (2008) established that uptake of N and P by corn plants increased significantly with both N and P applications. Notably the seasonal average of N concentrations measured in the tissue samples from corn in FYW compost treatment plots did not differ significantly from the check plots (2xSEM=0.0886). Findings from E1 that FYW compost did not contribute significant amounts of plant available N to soil over an 88 d incubation further corroborate these results. Interestingly the average concentration of N in the tissue samples collected from the NPK plots in July was statistically higher than the average concentrations measured in FYW and check plots. Tissue sample collection in July closely followed the top dress of inorganic NPK fertilizer that was only applied to NPK plots. Also, results show that there was no significant difference between tissue N concentrations measured at harvest between all FYW treatments, NPK and check. Although, N measured in tissue samples collected from the FYW1.5 treatment plots were significantly higher than FYW1.0, FYW0.5, NPK and check. This result indicates a cumulative effect of the slow nutrient releasing FYW compost from the greatest application rate of FYW compost (36t $ha^{-1}$). FYW compost treatments on average did not increase the concentration of N in the corn plant as confirmed by higher concentrations of N in plant tissue samples from NPK and check plots. Incubation studies that characterize the release of plant available N from FYW compost over the long term may better quantify N contributions from FYW compost only.

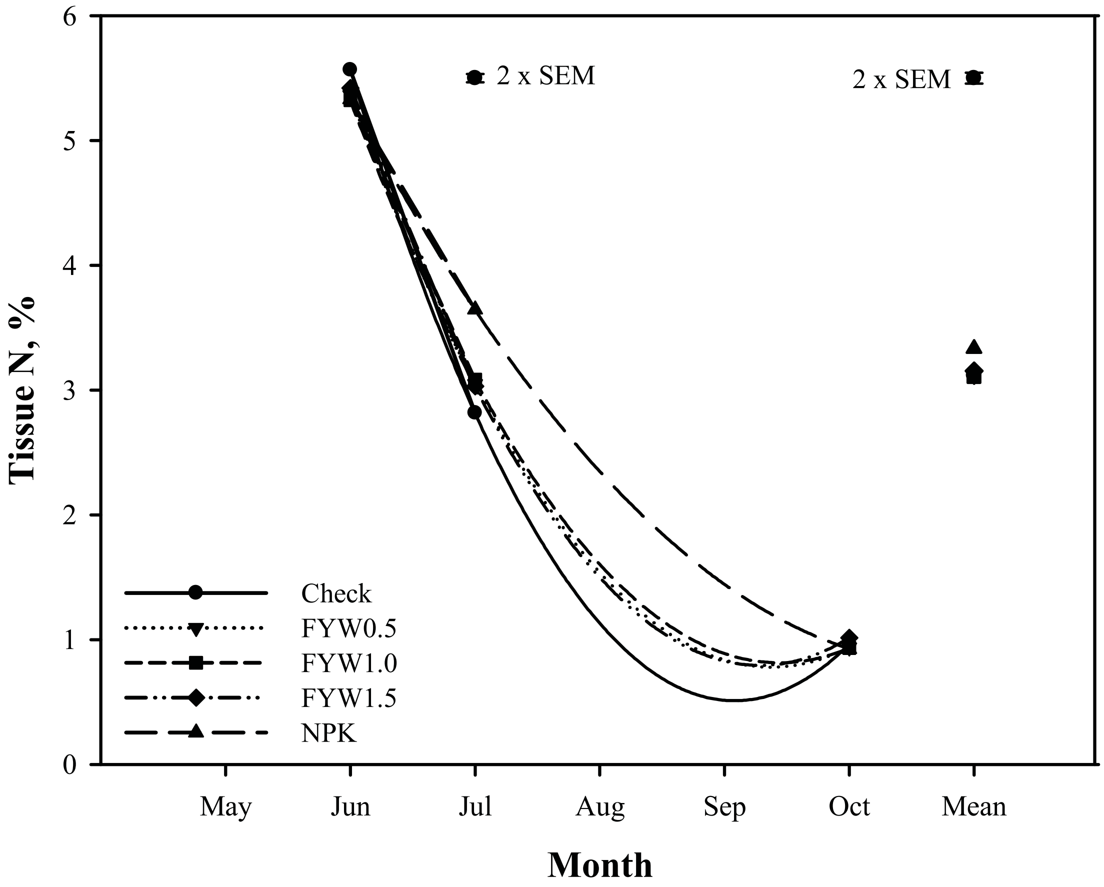

Figure 4.9 The combined average of 2008 and 2009 application years N concentrations (%) in plant tissue samples as collected over the growing season following application of food and yard waste (FYW) compost treatment rates, NPK treatment and check.

### 4.3.2.3 Stover Phosphorus

To compare the overall effect of FYW compost and NPK fertilizer application on the N and P content of and removal by the stover portion of the corn plant at harvest, averages from 2008 are provided in Table 4.14.

Table 4.14 Characteristics of corn stover at harvest including: yield (t $ha^{-1}$), N and P concentrations (%) in and total N and P removed (kg $ha^{-1}$) by following food and yard waste (FYW) compost and NPK fertilizer treatment applications in 2008.

| **Treatment** | **Yield (t $ha^{-1}$)** | **N (%)** | **P (%)** | **P removed (kg $ha^{-1}$)** | **N removed (kg $ha^{-1}$)** |
|---|---|---|---|---|---|
| **FYW0.5** | 7.96 | 1.00 | 0.10 | 7.41 | 83.03 |
| **FYW1.0** | 7.81 | 1.11 | 0.13 | 9.92 | 73.85 |
| **FYW1.5** | 7.48 | 1.12 | 0.11 | 8.06 | 79.26 |
| **NPK** | 8.07 | 1.01 | 0.09 | 6.69 | 81.43 |

Higher concentrations of P were found in the stover portion of the harvested plants grown with FYW compost than when compared to NPK application ($p<0.001$); however, no significant differences were found between application rates of FYW compost (2xSEM=0.0268) (Figure 4.10). Sneller and Laboski (2009) found that corn responded to P application by an increase in biomass and P uptake at harvest. Corn shoot P significantly correlates with shoot N, whereby increased N availability enhances P uptake (Mkhabela and Warman, 2005; Hussaini *et al.*, 2008). Results from E1 indicate the net mineral N at 88 d was significantly greater for FYW compost application compared to soil only, with a tendency to increase with increasing FYW application rates. The P concentrations measured in the stover at harvest reflect the nutrient requirements during the reproductive stages for starch accumulation and filling kernels. Thereby, similar to conclusions from tissue P concentrations, the FYW compost provided a slower release of nutrients over the growing season than NPK fertilizers; therefore, providing the nutrients needed by the crop later in the season for maturing processes.

There was no significant treatment effect on N concentrations in the stover portion of the corn plant collected at harvest.

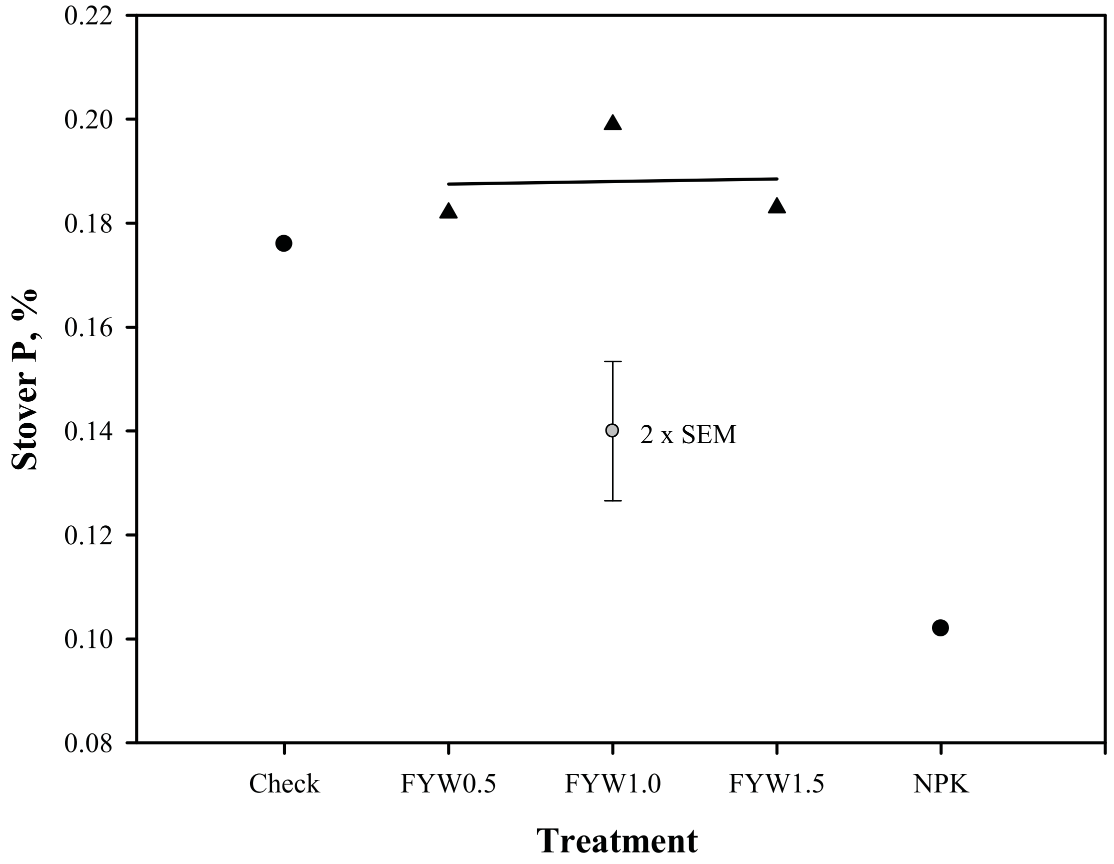

Figure 4.10 Corn stover phosphorous (P) concentrations (%) measured at harvest as averaged for 2008 and 2009 application years data following food and yard waste (FYW) compost and NPK treatments and for the check plots in 2009.

### 4.3.2.4 Nutrient Removal In Grain

Less P was removed in grain than had been applied by all sources for all treatments. Mineralization of P results, from E1, indicate that the availability of P from the FYW compost increased with increasing application rates and that FYW1.5 supplied amounts of P necessary for corn growth. Amounts of N applied from all sources and removed by the grain portion of the plant following NPK and FYW treatment application and from check plots for 2008 and 2009 can be found in Figure 4.11.

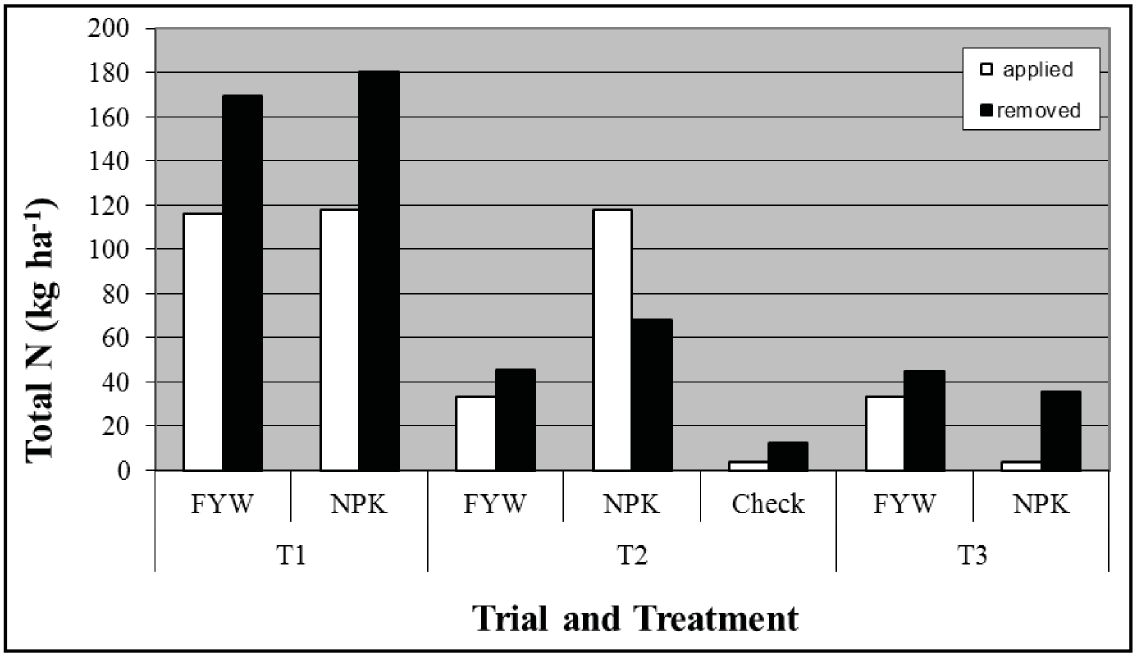

Figure 4.11 Total N applied (kg ha$^{-1}$) by all sources and (kg ha$^{-1}$) removed by corn grain from food and yard waste (FYW) compost and NPK fertilizer treatments applied to Trial 1 in 2008, Trial 3 in 2009 and Trial 2 in 2009 with check as well.

Grain corn grown in Eastern Canada removes in the range of 112-168 kg ha$^{-1}$ N and 62-74 kg ha$^{-1}$ $P_2O_5$ based on projected yields of 9.4 t ha$^{-1}$ (Canadian Fertilizer Institute, 2001). Findings from the present study indicate that, in 2008, all treatments resulted in considerably more N removed by grain corn than had been applied by; dairy manure, FYW compost and inorganic fertilizers (Figure 4.11). Check plots established in 2009 yielded similar amounts of grain and removed similar amounts of N in the grain as the FYW0.5 treatment with plots only receiving nutrient contributions from the 2007 dairy manure applications (4, 5, 8 kg ha$^{-1}$ of N-$P_2O_5$-$K_2O$). Also, the N mineralization results from E1 indicated that FYW compost only, applied at rates between 12 – 36 t ha$^{-1}$ would not provide sufficient N to meet corn N removal requirements. Removal of N in grain similarly exceeded that applied in both the NPK and FYW treatment plots therefore; this affect cannot be attributed to FYW compost or NPK fertilizer alone. Plant available nutrients in 2008 from the soil, previous manure applications and the preceding forage crop may have contributed significantly more N than expected. There is currently no standard soil test for N in Atlantic Canada due to the difficulty in predicting the rate of various N processes (Burton *et al.,* 2003). Spring soil nitrate testing is becoming more common in corn grain production along with tissue samples to determine sufficient growing season N availability (Burton *et al.,* 2003). As mentioned in section 4.3.1.1, the conditions for crop growth and N mineralization were more favourable in 2008 than when compared to 2009 (Table 4.7). These favourable conditions may have resulted in the variability between years in terms of grain yields and amounts of nutrients removed. Notably, the 2008 and 2009 grain nutrient analysis revealed that their N and P concentrations were not significantly different. Hussaini *et al.* (2008) reported that N and P application has a greater impact on grain yield than it does on nutrient concentration in the grain. Nutrient concentrations in a plant depend upon the influence of other nutrients present in the soil and their direct or indirect effect on the applied nutrient at increasing growth and yield (Hussaini *et al.,* 2008). Nitrogen mineralization conditions were more favourable in 2008, and both the 2007 dairy manure application and ploughed down green manure crop would have contributed more plant available N in 2008 therefore contributing to the increased yields and greater removal of N by grain corn exhibited by all plots.

### 4.3.3 Immediate and Residual Effects of FYW Compost on Soil

Data are reported graphically only when there were significant ($p<0.05$) treatment effects and for all other response variables there were no significant treatment effects.

Soil M3P, OM content, CEC and pH values were used as indicators to identify the overall treatment effect of FYW compost application on soil properties in the year of application for 2008 and 2009 and are provided in Table 4.15. Data for 2008 and 2009 were combined and averaged for each treatment at each sampling occasion; to identify the average change in soil measures over a growing season following application. In 2008 there were no check plots therefore means were predicted for the average of 2008 and 2009 based upon 2008 data and blocked by year. Soil M3P content, OM, CEC and pH values were also used as indicators to identify the overall residual effect of FYW compost treatment applications on soil properties in the second year following application for 2009 and are provided in Table 4.16. Notably, considerable variability exists between seasons, years and treatment repetitions and has resulted in inconsistent soil pH and OM results. These results do not follow a particular trend that corresponds to treatment applications and therefore treatments were determined to have no impact on these soil properties. Notably, fluctuations in soil pH during the incubation of FYW compost and soil mixtures, E1, were also found although trends between the laboratory and the in-field experiments were not similar. Data is presented in the following section although caution must be exercised when interpreting the soil pH and OM findings and/or applying them to future research.

Table 4.15 Comparison of seasonal means for soil properties (pH, CEC, OM and M3P) measured over and averaged for the 2008 and 2009 application year growing seasons following FYW, NPK and check treatment applications (means highlighted in bold are significantly different than the NPK treatment, based upon 2 x SEM).

| | | **FYW0.5** | | **FYW1.0** | | **FYW1.5** | | **NPK** | | **Check** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **08** | **09** | **08** | **09** | **08** | **09** | **08** | **09** | **08** | **09** |
| **pH** | **May** | 6.23 | 6.43 | 6.3 | 6.45 | 6.28 | 6.5 | 6.2 | 6.28 | N/A | 6.53 |
| | **June** | 6.38 | 6.38 | 6.15 | 6.33 | 6.33 | 6.23 | 6.05 | 5.93 | | 6.10 |
| | **July** | 6.25 | 6.68 | 6.18 | 6.63 | 6.28 | 6.63 | 6.23 | 6.25 | | 6.53 |
| | **October** | 6.38 | 6.73 | 6.4 | 6.85 | 6.43 | 6.88 | 6.43 | 6.25 | | 6.50 |
| **Mean** (SEM = 0.073) | | **6.43** | | **6.41** | | **6.44** | | 6.20 | | 6.32 | |
| **OM** (%) | **May** | 3.20 | 3.10 | 3.10 | 3.20 | 3.20 | 3.20 | 3.40 | 3.40 | N/A | 3.20 |
| | **June** | 3.10 | 3.10 | 3.00 | 3.10 | 3.00 | 3.10 | 2.90 | 3.20 | | 3.10 |
| | **July** | 3.40 | 2.80 | 3.50 | 3.30 | 3.60 | 3.70 | 3.60 | 3.40 | | 3.10 |
| | **October** | 3.30 | 3.30 | 3.20 | 3.30 | 3.20 | 3.40 | 3.30 | 3.50 | | 3.20 |
| **Mean** (SEM = 0.055) | | 3.16 | | 3.20 | | 3.29 | | 3.23 | | 3.14 | |
| **CEC** (meq 100gm$^{-1}$) | **May** | 11.6 | 11.9 | 12.1 | 12.3 | 12.2 | 12 | 12.3 | 12.5 | N/A | 12.2 |
| | **June** | 15 | 11.9 | 13.6 | 11.8 | 14.4 | 12.1 | 13.9 | 11.7 | | 11.6 |
| | **July** | 12.8 | 12.1 | 12.9 | 12.5 | 14 | 12.4 | 13.1 | 11 | | 11.5 |
| | **October** | 12.3 | 12.3 | 12.5 | 13 | 12.3 | 13.7 | 12.2 | 11.7 | | 11.6 |
| **Mean** (SEM = 0.257) | | 12.47 | | 12.59 | | **12.88** | | 12.29 | | 12.09 | |
| **M3P** (kg ha$^{-1}$) | **May** | 228 | 277 | 209 | 291 | 227 | 299 | 217 | 199 | N/A | 282 |
| | **June** | 311 | 392 | 349 | 383 | 308 | 422 | 315 | 289 | | 460 |
| | **July** | 305 | 365 | 281 | 409 | 353 | 397 | 257 | 278 | | 314 |
| | **October** | 315 | 428 | 321 | 435 | 313 | 533 | 267 | 284 | | 324 |
| **Mean** (SEM=18.95) | | **328** | | **335** | | **356** | | 263 | | **311** | |

Table 4.16 Comparison of seasonal means for pH, CEC (meq 100gm$^{-1}$), OM (%) and M3P (kg ha$^{-1}$) as measured over the second (2009) growing season following treatment applications in 2008 (means highlighted in bold are significantly different than the NPK treatment, based upon 2 x SEM).

| | Treatment | May | June | July | October | Mean | SEM |
|---|---|---|---|---|---|---|---|
| **OM**<br>(%) | FYW0.5 | 3.05 | 3.05 | 3.20 | 3.18 | 3.12 | **0.152** |
| | FYW1.0 | 2.93 | 3.15 | 3.23 | 3.30 | 3.15 | |
| | FYW1.5 | 3.08 | 3.10 | 3.20 | 3.20 | 3.14 | |
| | NPK | 3.08 | 3.03 | 3.18 | 2.98 | 3.07 | |
| **CEC**<br>(meq 100gm$^{-1}$) | FYW0.5 | 13.03 | 11.25 | 12.10 | 11.37 | 11.94 | **0.342** |
| | FYW1.0 | 13.12 | 11.72 | 12.05 | 11.65 | 12.14 | |
| | FYW1.5 | 13.15 | 11.97 | 12.70 | 12.32 | 12.54 | |
| | NPK | 12.80 | 11.82 | 12.40 | 11.45 | 12.12 | |
| **pH** | FYW0.5 | 6.68 | 6.28 | 6.58 | 6.45 | 6.49 | **0.117** |
| | FYW1.0 | 6.60 | 6.20 | 6.50 | 6.53 | 6.46 | |
| | FYW1.5 | 6.78 | 6.30 | 6.60 | 6.63 | 6.58 | |
| | NPK | 6.53 | 6.30 | 6.50 | 6.45 | 6.44 | |
| **M3P**<br>(kg ha$^{-1}$) | FYW0.5 | 305 | 315 | 321 | 382 | **331** | **25.15** |
| | FYW1.0 | 305 | 383 | 318 | 348 | **338** | |
| | FYW1.5 | 317 | 336 | 339 | 401 | **348** | |
| | NPK | 240 | 252 | 266 | 270 | 257 | |

#### 4.3.3.1 Mehlich III Extractable Soil Phosphorus

The measures of soil M3P content in check plots decreased over the growing season and were significantly lower than when FYW compost or NPK fertilizers were applied ($p<0.001$) (Table 4.17). Singer *et al.* (2004) also found that applications of composted swine manure, very similar in % N (1.13), % P (0.61) and % C (14.83) content to the presently researched FYW compost, significantly increased soil M3P statistically more than plots without compost. The present research determined that grain harvested from the corn grown in check plots removed an average of 18.9 kg P ha$^{-1}$ and had not received NPK fertilizers or FYW compost. It is expected that corn’s removal of nutrients from the soil with no replenishment from a nutrient source would deplete soil M3P concentrations over the growing season. The seasonal average of soil M3P concentrations from check plots, 310 kg M3P ha, was not significantly lower than FYW compost treatments and would still be sufficient for corn removal purposes. Results from the check plots indicate that multiple years of nutrient removal by a crop without further application would be necessary to reduce the initial medium to high soil M3P concentrations.

Table 4.17 Significant relationships identified through an ANOVA between soil response variables and treatments as identified for the application and residual years, as represented by $p$-values $< 0.05$.

| | **Check vs. FYW & NPK** | **NPK vs. FYW** | **Linear Compost** |
|---|---|---|---|
| Response variable | **Application Year** | | |
| **M3P** | **p < 0.001**** | **p = 0.002***<br>**p = 0.016**** | |
| **CEC** | **p = 0.001**** | **p = 0.001**** | **p = 0.012**** |
| **pH** | **p = 0.010**** | **p = 0.020**** | |
| **OM** | **p = 0.002**** | | |
| Response variable | **Residual Year** | | |
| **M3P** | | **p = 0.020*** | |
| **CEC** | | **p = 0.028**** | |

* indicates a significant treatment response to the seasonal average of response variable.
**indicates a significant treatment response to measurements over the season

Food and yard waste compost application caused greater increases in soil M3P as the growing season progressed than when compared to NPK application ($p=0.016$). As well, applying FYW compost resulted in significantly higher seasonal averages of soil M3P (328-356 kg ha$^{-1}$) than when compared to the NPK treatment (263 kg ha$^{1}$) ($p=0.002$) (Figure 4.12 and Table 4.15). These results indicate that FYW compost supplied more P than NPK fertilizers even though results from E1 indicate only the highest FYW application rate mineralized similar amounts of plant available P to the NPK fertilizer treatment. The 88 d incubation did not show a trend for P mineralization from FYW compost to cease or decline considerably and therefore a five month growing season may result in greater amounts of mineralized P. This is evident by the fact that the grain corn, that had received the NPK treatment, removed approximately 2.7 kg M3P ha$^{-1}$ more than grain that had received FYW compost applications. But, applying the FYW compost resulted in greater amounts of soil M3P that were approximately 50 kg M3P ha$^{-1}$ more than from NPK inorganic fertilizers. The lack of N supply from the FYW compost resulted in reduced yields and therefore reduced P removal by the grain.

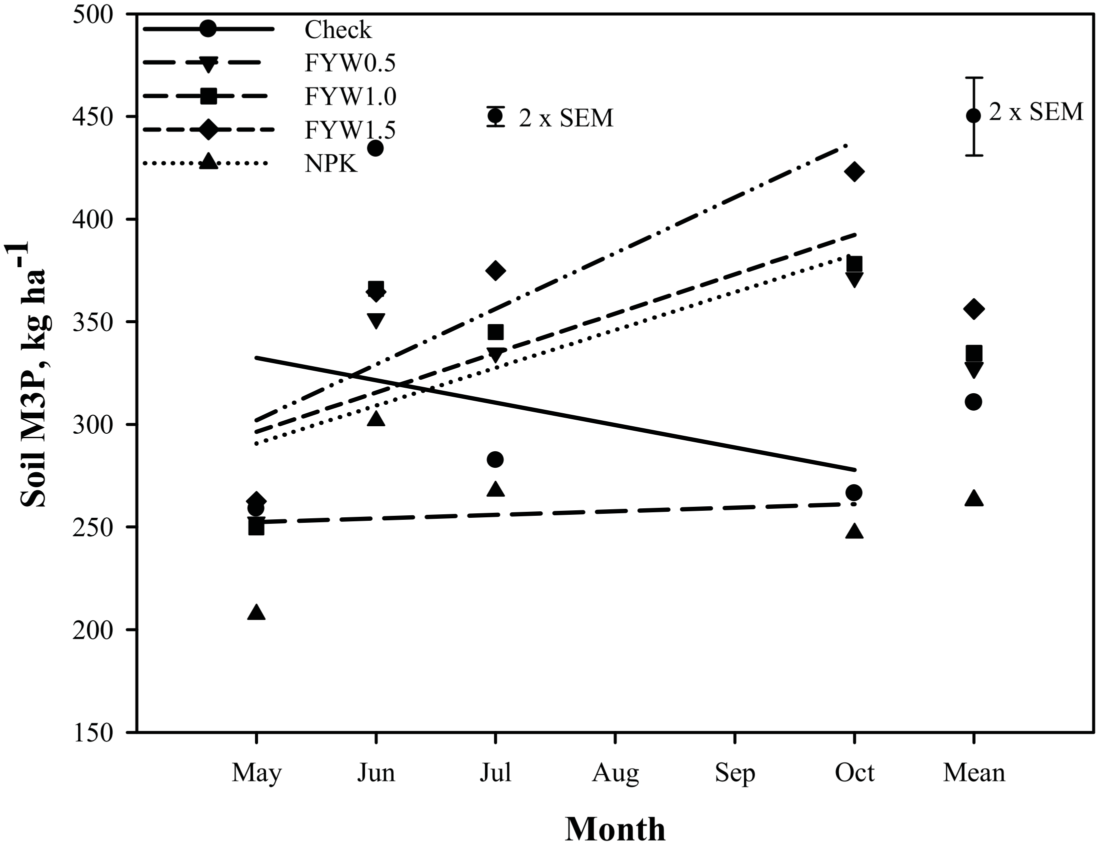

Figure 4.12 Growing season measurements of soil M3P from average of samples collected throughout the 2008 and 2009 growing seasons following application of food and yard waste (FYW) compost, NPK and check treatments.

Results also identify linear trends between both time and soil M3P and the rate at which the FYW compost was applied. As the rate of compost applied increased so did the soil M3P content; as the season progressed and on average for the whole season, although not significantly. These results are substantiated by trends in E1 where soil M3P concentrations and their rate of increase both increased with larger FYW compost application rates (Table 3.3). Eghball and Power (1999) found that soil M3P content was directly related to total P applied with compost. In the present study the FYW0.5 treatment was aimed to supply half the plant available P as FYW1.0 and FYW1.5 was aimed to supply one and a half times more than FYW1.0. The seasonal averages of soil M3P were not statistically different between FYW compost rates in the field. Although, the laboratory experiment E1, proved the FYW0.5 to mineralize approximately half of that from the FYW 1.0 but the FYW 1.5 mineralized approximately 1.7 times more the FYW1.0. The magnitude of increases in plant available P were greater as the application rate increased but this effect may be short lived. A decreasing trend in P mineralization over the latter part of the incubation of FYW 1.5 shows that larger application rates may result in greater P availability but only during the initial part of the growing season. Food and yard waste compost application may result in higher levels of plant available P but if compensated with an additional N source yields may increase and result in greater removal of P.

Residual effects of FYW compost application resulted in significantly higher seasonal averages of soil M3P (331-348 kg ha$^{-1}$) (Table 4.16) than when compared to residual effects of the NPK treatment (257 kg ha$^{-1}$) (p=0.020) (Figure 4.13). The lack of residual effect of inorganic fertilizers on plant available P was also documented by Rodd *et al.* (2000) and is due to readily available nutrients from inorganic fertilizers and their removal by crops over their application year growing season. Interestingly, the soil M3P levels were higher in the second year following FYW compost application than in the previous year when treatments were first applied. Rodd *et al.* (2000) found that the residual effect of an organic addition on soil M3P was greater following compost addition when compared to fertilizer. Eghball *et al*. (2004) also found residual effects of compost addition to result in elevated levels of plant available P concentrations and that this effect can remain for several years. Soil M3P concentrations increased over the growing season in response to previously applied FYW compost application and concentrations increase with increasing application rate as well. The analysis of variance did not identify these relationships to be significant but, in accordance with findings from E1, implications are that also in the year following application of FYW compost soil M3P levels increase with increasing application rate. Rodd *et al.* (2000) found that in the second growing season following MSW compost application soil M3P content increased with increasing compost application rate. Residual amounts of M3P from FYW compost applications were underestimated and in this case of high soil P concentrations additional P did not need to be applied in the year following application to deliver adequate P to corn (Rodd *et al.,* 2000). Similar recommendations may be made from the present study in that the amount of plant available P in the year following application increases with the amount of P previously applied with compost and that this residual P may be sufficient for crop growth.

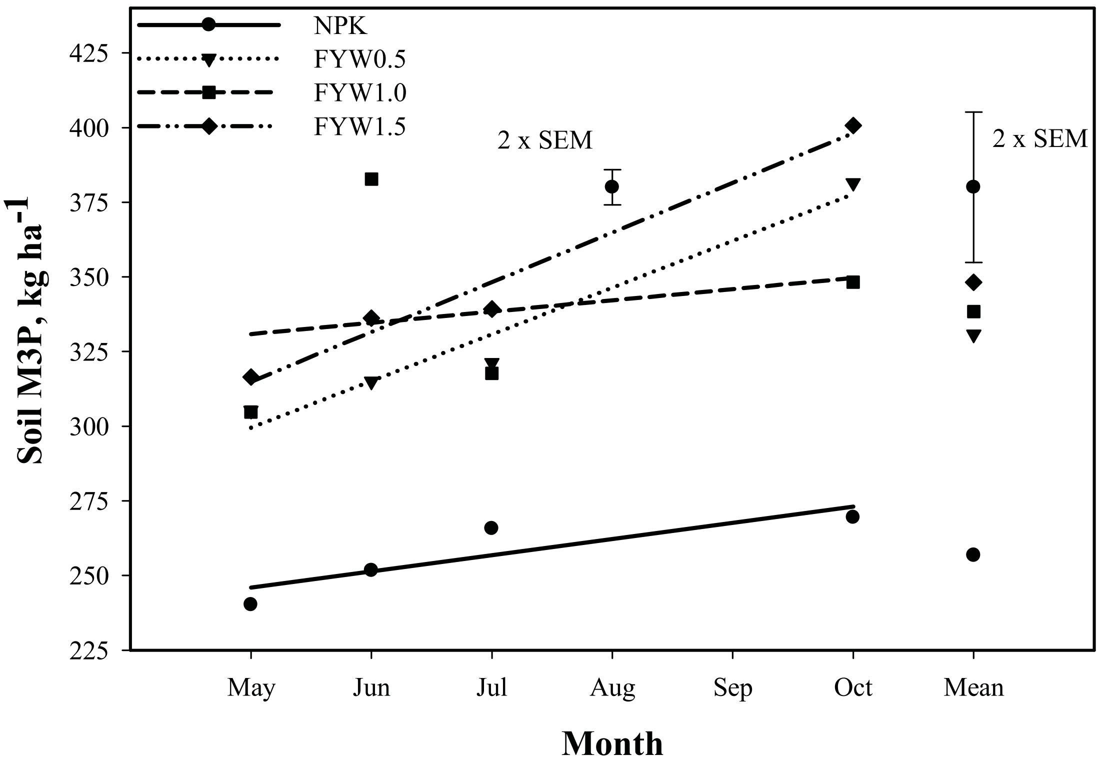

Figure 4.13 Measures of soil M3P from soil samples as collected over the second growing season following application of food and yard waste (FYW) compost and NPK treatments in 2009.

#### 4.3.3.2 Soil CEC

As the season progressed, the CEC of the soil in check and NPK plots decreased (p=0.001) whereas the CEC increased with FYW application (p=0.001) (Figure 4.14). A significant linear response by soil CEC to the rate of FYW compost applied was also identified (p=0.012) (Table 4.17). A soil's CEC is the capacity for it to exchange of cations between it and its solution and is linearly related to the percent clay and OM (Burton *et al.,* 2003). Cation exchange capacity is strongly correlated to soil electrical conductivity (EC), a measure of soluble ions (salts) in the soil, and MSW compost application has been found to increase soil EC levels in relation to feedstock and facilities composting procedures (Hargreaves *et al.*, 2008). Other studies have also identified soil

EC levels to be related to application rates and that soil EC increases as more compost or manure is applied due to its high OM content (Eghball, E., 2002 and Eghball *et al.,* 2004), similar to findings from this present study.

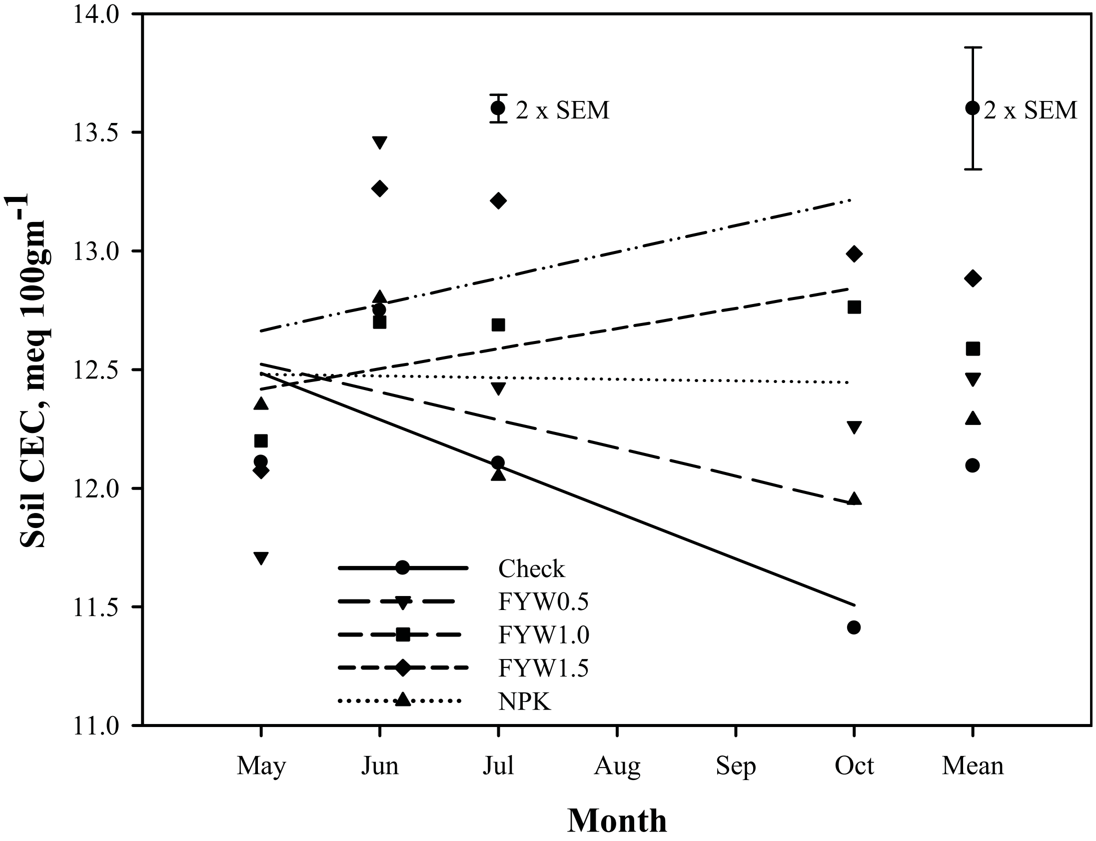

Figure 4.14 Average measures of soil CEC from soil samples collected over the application year growing season for food and yard waste (FYW) compost, NPK and check treatments in 2008 and 2009.

The analysis of variance indicated that residual effects of FYW compost on soil CEC were significantly greater than the residual effects of NPK fertilizers (p=0.028) (Figure 4.15). Soil OM responded similarly to NPK fertilizer application and further substantiates findings that soil CEC is linearly related to soil OM in that as the percent OM content of the soil decreases so does the soil CEC. This decrease in both OM content and soil CEC could result in reduced replenishing of plant available nutrients and the soils associated nutrient holding capacity. An increase in soil CEC exhibits the soils enhanced ability to exchange cations, notably P is an anion. MSW composts are known to be poor suppliers of plant available N but an increase in soil CEC would increase the soils ability to bind N to the soil particles and retain it for subsequent plant uptake. Applying FYW compost increases soil CEC in the year of application thereby increasing the soils ability to exchange N with the plant. Even though the compost may not be a large supplier of plant available N increasing soil CEC may enable enhanced exchange of N with the soil solution and plant in residual years.

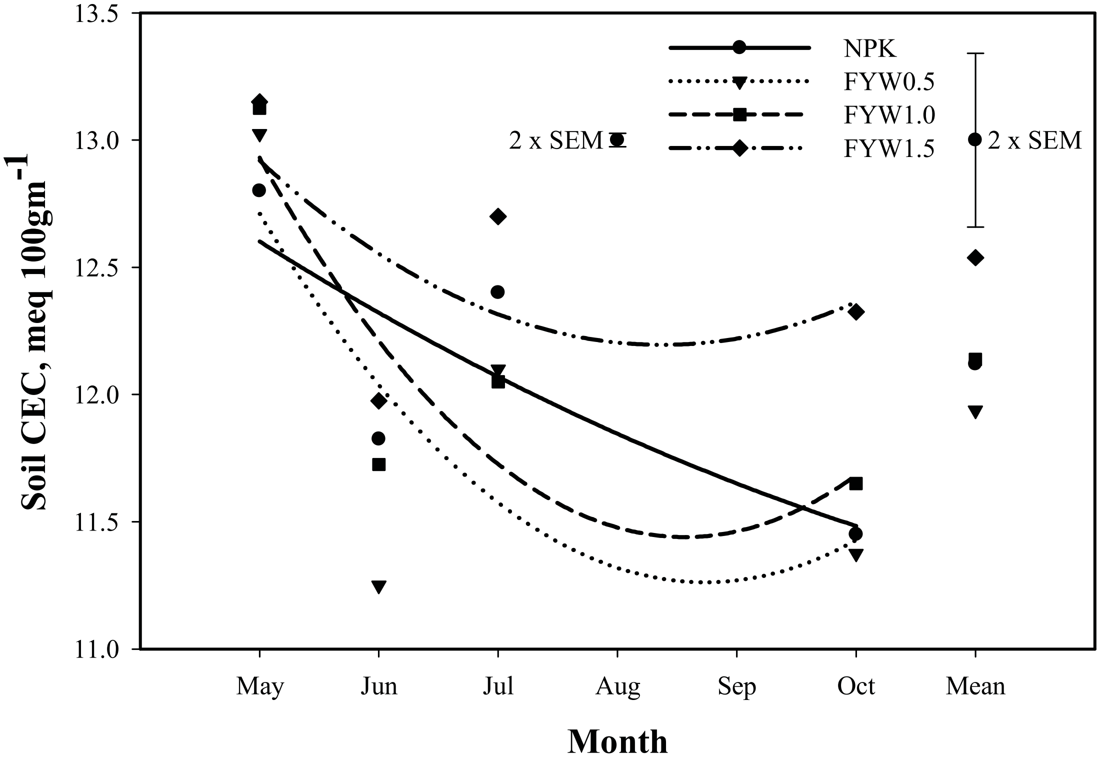

Figure 4.15 Measures of soil CEC from soil samples collected over the second growing season following application of food and yard waste (FYW) compost and NPK treatments in 2009.

#### 4.3.3.3 Soil pH

The analysis of variance identified that FYW compost and NPK fertilizer applications caused significantly greater increases in soil pH than the check plots that exhibited very little change in soil pH as the season progressed (p=0.010) (Table 4.17). Findings that MSW compost increased soil pH when compared to untreated controls (Ozores-Hampton *et al.*, 2000; Sullivan *et al.,* 2002; Mkhabela and Warman, 2005; Hargreaves *et al.*, 2008) are further substantiated by these results. Eghball (2002) found that one-time compost applications increased surface soil pH and significant linear trends in treatment application rates has been found by many (Eghball, 2002; Hargreaves, 2008; Rodd *et al.,* 2008). Within the present study the change in soil pH over the growing season, from FYW compost application, tended to be greater than the acidic granular inorganic NPK fertilizer although not statistically. There is also no evidence that soil pH increases with increasing FYW compost application rate. FYW compost application resulted in higher soil pH values over the season (p=0.020) but the seasonal average did not differ between FYW and NPK treatments (Figure 4.16). A considerable amount of variability exists within this data therefore making it difficult to draw definitive conclusions. Due to this variability in the data the results of E1 and E2 only suggest compost to be able to maintain or at least not decrease initial soil pH as much as chemical fertilizer, confirming the results of Mkhabela and Warman (2005), Eghball *et al.* (1999) and Eghball, B. (2002).

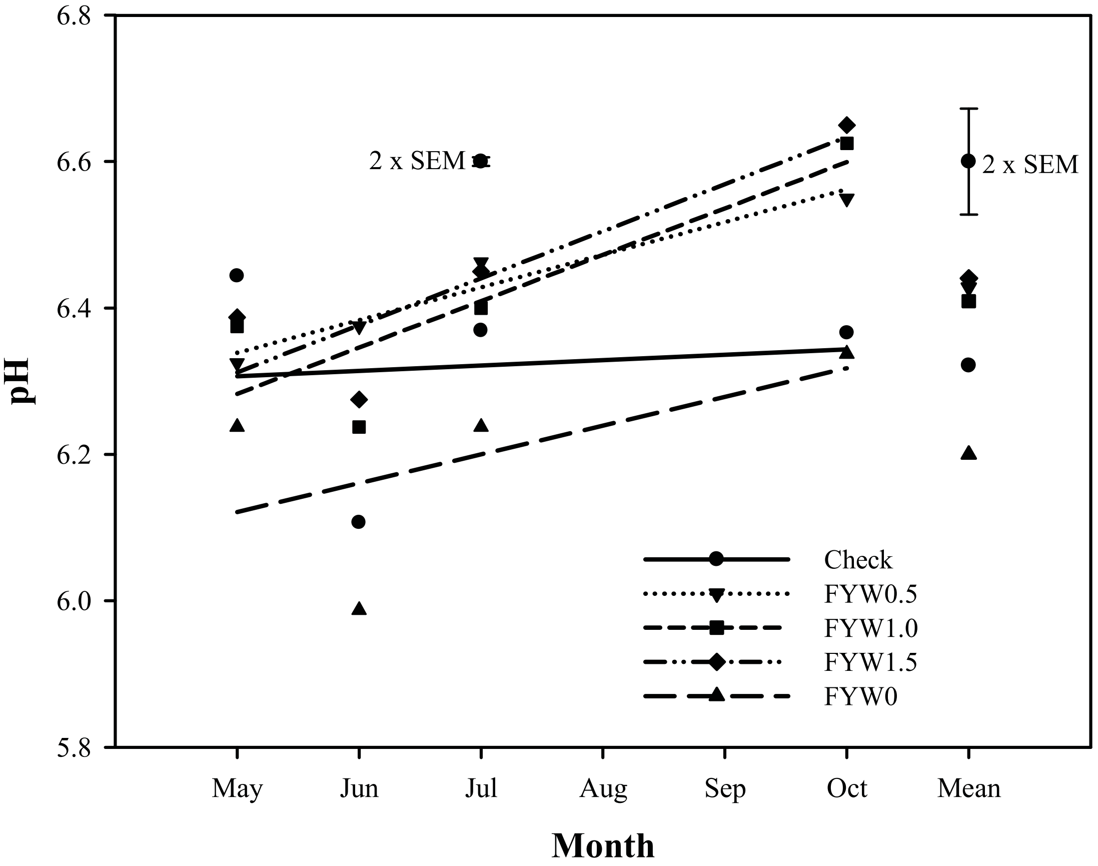

Figure 4.16 Average measures of soil pH from soil samples collected over the application year growing season for food and yard waste (FYW) compost, NPK and check treatments in 2008 and 2009.

#### 4.3.3.4 Soil Organic Matter

The analysis of variance indicated that the FYW compost and NPK fertilizer applications increased soil OM content more than check plots, as measured in soil samples collected from treatment application in May to harvest in October (p=0.002) (Table 4.17) (Figure 4.17). Many other studies have found repeated applications of MSW compost to increase soil OM (Singer *et al.,* 2004; Hargreaves *et al.,* 2008; Rodd *et al.,* 2008) and quite often this effect increased with increasing application rates. Although in the present study, the rate of FYW compost application did not significantly affect soil OM content. Fertilizer application, especially N fertilizers, can increase soil organic matter in two ways; by providing micro-organisms with easy-to-use N components thereby increasing micro-organisms' activity and thus decomposition of organic matter and by increasing crop yield and crop residue returned to soil (Graham *et al.,* 2002).

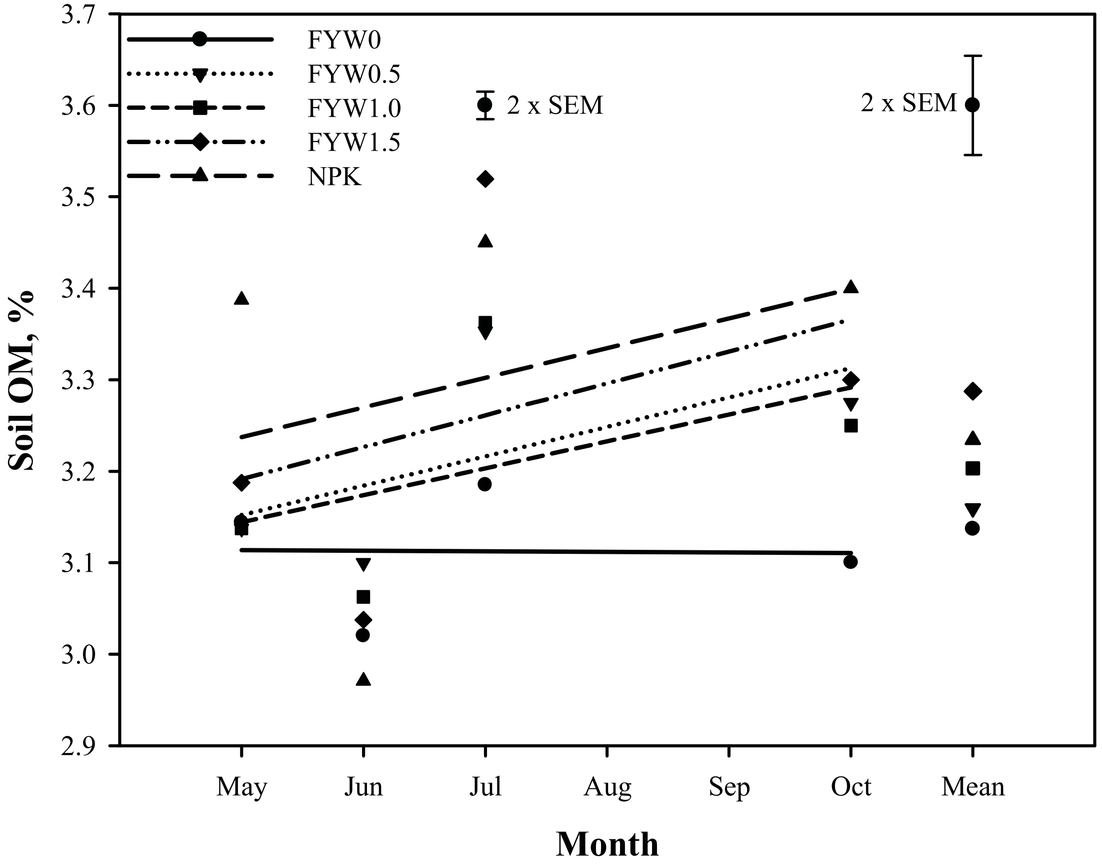

Figure 4.17 Measures of soil organic matter (OM) from soil samples collected from the 2008 and 2009 application year growing seasons following food and yard waste (FYW) compost, NPK and check treatments.

Eghball *et al.* (2004) found that improved soil properties following compost application lasted for several years and the quantity of microbial biomass C was greater for compost than control or inorganic fertilizer. Ozores-Hampton and Obreza (1994) found higher soil OM levels in previously applied compost treatment plots than the control and OM levels increased with compost application rate. In the present study, seasonal soil OM averages were not different between residual FYW compost and NPK fertilizer plots or between rates of previously applied FYW compost. Due to the variability that exists within the soil OM data it is difficult to draw conclusive results to build upon with future studies. The results from in-field trials do indicate that FYW compost and NPK inorganic fertilizers have the ability to increase soil OM content in the year of application but that this effect does not increase with increasing compost application rate nor does the effect last for more than one season.

## 4.4 Conclusions

### 4.4.1 Corn Grain Characteristics

The 2008 yields ranged between 8.95-9.25 t ha$^{-1}$ following FYW treatment application and 9.6 t ha$^{-1}$ following NPK fertilizer application and were not significantly different. In 2009, corn grain yields from all treatments represented only 34 – 54% of those from their treatment counterparts in 2008. The variability between all treatments yields in 2008 and 2009 can be attributed to favourable N mineralization conditions, dairy manure applications and a green manure crop ploughed down that all contributed greater amounts of N during the 2008 growing season. On average, in the year of application, NPK fertilizer plots yielded significantly more corn grain and grain removed greater quantities of N and P than FYW compost. In 2009, corn grain yields were not significantly different between plots that had received compost in the current year or in the previous year. Applications of FYW compost had significant effects on grain yield and removal of N by grain in the second growing season following application. FYW compost can be expected to yield similar amounts of corn grain and supply similar amounts of plant available nutrients in the first and second year following application.

The FYW compost treatments had a more significant effect on tissue, stover and grain P concentrations, than compared to the NPK treatment, indicating greater contributions of plant available P than estimated. Total amounts of P and N removed by grain were greatest following NPK fertilizer application, as a result of higher grain yields. Basing application rates more appropriately on accurate nutrient availability from FYW compost should enable application rates that result in yields similar to and N and P uptake exceeding those from NPK fertilizer application.

### 4.4.2 Soil Properties

Considerable variability existed within the soil properties data that included variability between treatment repetitions and between samples dates meaning that it is difficult to draw conclusive inferences in regards to this data. Although, results indicated that soil properties including; M3P, pH, CEC and OM were found to increase significantly over the year of FYW compost application more than those following the NPK treatment. Soil M3P content was the only soil property found to have a higher seasonal average, in the year of application, as a result of FYW compost rather than NPK application. Soil analyses collected over the growing season following application identified that the soil CEC responded linearly to the rate of FYW compost application. Residual amounts of plant available P contributions from FYW compost application were underestimated and in the case of high soil P concentrations additional P does not need to be applied in the year following application to deliver adequate P to corn.

# Chapter 5.0 Conclusions

A laboratory incubation study revealed food and yard waste (FYW) compost to steadily release plant available nitrogen (N) and phosphorus (P) over three months, following its incorporation into a coarse, sandy loam soil. Concentrations of mineral N were significantly greater following FYW compost application and showed trends to increase past the 88 day (d) incubation. Although, FYW compost was not considered to be a significant source of N, as demonstrated by the mere 0.1% of the total compost N being available over the 88 d. The highest FYW compost application rate of 36 t ha$^{-1}$ supplied only 1.24 kg plant available N ha$^{-1}$ and therefore would need to be supplemented with an additional source of N to meet crop requirements. Concentrations of Mehlich III extractable phosphorus (M3P) were considered to be constant over the 88 d incubation with no significant increases or decreases with the exception of FYW1.5 whose availability of P increased significantly over the 88 d. The availability of P at application and on Day 88 was greater for FYW1.0 and FYW1.5 with the FYW0.5 rate not differing significantly from the soil only control. On average, the availability of P was measured to be 3% of the total compost P applied; FYW0.5 mineralized 3.61 kg ha$^{-1}$, FYW1.0 mineralized 15.12 kg ha$^{-1}$ and FYW1.5 delivered 39.5 kg plant available P ha$^{-1}$. In summary, these results show that sufficient plant available P, for corn removal purposes, can be expected to mineralize over the first growing season following FYW compost application. Nitrogen is far slower to release from this well decomposed FYW compost and will not mineralize sufficient amounts of plant available N for corn removal purposes in the first year of application. As field conditions are not repeatable, this laboratory incubation experiment allows fellow researchers to carry out similar incubations of composts or other soil amendments thereby facilitating comparison of results in the future.

The results from the in-field trials showed that all treatments in 2008 had significantly higher grain yields and represented approximately twice the yields recorded in 2009. Notably, these reduced yields in 2009 were recorded from both the previously established 2008 residual plots and the newly established NPK fertilizer and FYW compost treatments. The contrast between corn grain yields in 2008 and 2009 is attributed to all treatments receiving a starter fertilizer in 2008, the difference between seasonal corn heat unit's (CHU), soil moisture and plant available nutrients from previous manure applications and the plough down of a green manure crop. In order to better isolate the effects from FYW compost on corn yields, nutrient uptake and removal and soil properties future similar research should be conducted in a field with less history of organic nutrient application.

On average, for both the 2008 and 2009 years of treatment application, the concentration of P measured in the stover and grain were far greater following FYW compost applications. Although, the NPK fertilizer treatment yielded greater amounts of stover and grain therefore the overall removal of P was greatest for NPK fertilizer applications. Notably, when yields were similar for all treatments in 2008 the FYW compost treatments resulted in greater amounts of P removed in the stover and amounts of P removed in grain were equal to those from NPK fertilizer applications. Also, in the second year following application FYW compost had a significant effect on yield, N and P removed in grain and soil M3P concentrations. 2009 data showed no significant difference between yields from plots receiving FYW compost in May 2009 or plots that had received FYW compost applications in May 2008. Therefore, FYW compost contributes plant available nutrients over the second (residual) growing season following application. Whereby nutrient uptake by corn continues into the reproductive stages, these results indicate a slower release of nutrients from the FYW compost in comparison to the readily available inorganic fertilizer nutrients. Increased yields achieved when FYW compost is matched with inorganic N fertilizer can be expected to result in greater amounts of P being removed by grain than when compared to NPK fertilizers only.

The effects on soil properties were significantly variable and although the results from FYW compost applications indicated increases in soil organic matter (OM), pH and cation exchange capacity (CEC) the variability found throughout the season, years and between plots make it difficult to draw conclusions. This FYW compost may help to neutralize acidic soils and, over a longer period of time, OM content of soils may also increase with multiple applications. Field trials carried out over multiple years that include many treatment repetitions on different soil types may help to minimize the variability in affects on soil properties found within this study.

Annual or biennial applications of 24 t ha$^{-1}$ of FYW compost to corn with an inorganic N fertilizer, such as ammonium nitrate, at planting could be expected to remove more P and yield similarly to NPK fertilizer only. Further research will need to be conducted to quantify long-term residual N and P contributions for better management of nutrients aimed to supply crops with their required nutrients and to reduce the impact on the environment. With FYW compost's potential to be a significant, organic source of plant available P and to improve soil properties in the long-term it would be most appropriately utilized for organic farming applications and for high P demanding crops such as strawberries.

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# Appendix A. Example Calculations

## Calculations for E1:

**1.** Volume of water to meet 60% water filled pore space (WFPS) in FYW1.5 treatment:

Required water = [% WFPS x (soil $d_b$ – compost $d_b$)] / (soil $d_b$ x compost $d_b$)
= [60 (2.65 -0.42)] / (2.65 x 0.42)
= 120.21563 mL 250 $g^{-1}$ compost and soil mixture
=120.21563 / 250g = 0.4808625 mL $g^{-1}$ compost soil mixture
= 0.4808625 x 4.687 g
= 2.25 mL distilled water to achieve 60% WFPS

Where:
Required water is the amount of water required to bring moisture level up to desired level in mL. % WFPS is the percentage of soil pore space to be water filled, equivalent to 60% for this experiment.

**2.** Calculation of oven-dry (OD) weight of food and yard waste (FYW) compost to add to each container to replicate the FYW1.5 treatment application rate:

g OD compost / 250g jar of soil =

$$\frac{\text{kg } P_2O_5}{\text{hafs}} \times \frac{\text{hafs}}{1500\text{m}^3} \times \frac{\text{m}^3}{1{,}000{,}000 \text{ cm}^3} \times \frac{\text{cm}^3}{\text{g OD soil}} \times \frac{1000\text{g OD soil}}{\text{kg OD soil}} \times$$

$$\frac{100\text{kg OD compost}}{\text{kg } P_2O_5} \times \frac{0.250 \text{ kg OD soil}}{\text{jar}} \times \frac{1000\text{g OD compost}}{\text{kg OD compost}}$$

Where:
2.254 % $P_2O_5$ in compost on a dry matter basis applied at the 36 t $ha^{-1}$, FYW1.5, treatment application rate = 2.254 kg $P_2O_5$ 100 $kg^{-1}$ compost x 36000 kg $t^{-1}$ = 811.44 kg $P_2O_5$ $hafs^{-1}$

$$\frac{811.44 \text{ Kg } P_2O_5}{\text{hafs}} \times \frac{\text{hafs}}{1500\text{m}^3} \times \frac{\text{m}^3}{1{,}000{,}000 \text{ cm}^3} \times \frac{\text{cm}^3}{1.28\text{g OD soil}} \times \frac{1000\text{g OD soil}}{\text{kg OD soil}} \times$$

$$\frac{100\text{kg OD compost}}{2.254 \text{ kg } P_2O_5} \times \frac{0.250 \text{ kg OD soil}}{\text{jar}} \times \frac{1000\text{g OD compost}}{\text{kg OD compost}} = \frac{4.69\text{g OD compost}}{250\text{g jar of soil}}$$

## Calculations for E2:

**1.** Nutrient contribution from semi-solid dairy manure applied to research area in 2007:

[1]$NH_4^+$-N available in year one following application =

manure application rate x kg $NH_4^+$-N $t^{-1}$ manure x $NH_4^+$-N retention coefficient

= 32 t $ha^{-1}$ x 2.2 kg $NH_4^+$-N $t^{-1}$x 0.25

= 18 kg $NH_4^+$ -N $ha^{-1}$

Organic N available in year one = 3.3 kg N $t^{-1}$-2.2 kg $NH_4^+$-N $ha^{-1}$=1.1 kg N $ha^{-1}$

Organic N available in year 2 = 1.1 kg organic N $ha^{-1}$ x 32 t $ha^{-1}$ x 0.1 = 4 kg N $ha^{-1}$

Total N available in year 2 = 18 kg N $ha^{-1}$ + 4 kg N $ha^{-1}$ = 22 kg N $ha^{-1}$

Organic N available in year 3 = 1.1 kg organic N applied x 32 t $ha^{-1}$ x 0.1 = 4 kg N $ha^{-1}$

[1] Available $P_2O_5$ relative to the original application =

manure application rate x kg $P_2O_5$ $t^{-1}$ x estimated $P_2O_5$ availability after application

$P_2O_5$ available in year 2 = 32 t $ha^{-1}$ x 2.4 kg $P_2O_5$ $t^{-1}$ x 0.30 = 23 kg $P_2O_5$ $ha^{-1}$

$P_2O_5$ available in year 3 = 32 t $ha^{-1}$ x 2.4 kg $P_2O_5$ $t^{-1}$ x 0.10 = 8 kg $P_2O_5$ $ha^{-1}$

[1] Available $K_2O$ relative to the original application =

manure application rate x kg $K_2O$ $t^{-1}$ x estimated $K_2O$ availability after application

$K_2O$ available in year 2 = 32 t $ha^{-1}$ x 3.1 kg $K_2O$ $t^{-1}$ x 0.9 = 89 kg $K_2O$ $ha^{-1}$

$K_2O$ available in year 3 = 32 t $ha^{-1}$ x 3.1 kg $K_2O$ $t^{-1}$ x 0.05 = 5 kg $K_2O$ $ha^{-1}$

**2.** Estimation of Nutrient contributions from FYW compost treatment application rate, FYW1.0, as applied to T1 in 2008:

Where:
The nutrient content of FYW compost was assumed to not be fully available in the year of application; therefore assumptions of availability of nutrients were made as follows:

[2]10% of N available = (1.215 % N / 100) x 1000 x 0.10 = 1.22 kg N $t^{-1}$

[2]15% of $P_2O_5$ available = (0.718 % $P_2O_5$ / 100) x 1000 x 0.15 = 1.08 kg $P_2O_5$ $t^{-1}$

[2]40% of $K_2O$ available = (0.278 % $K_2O$ / 100) x 1000 x 0.40 = 1.11 kg $K_2O$ $t^{-1}$

Therefore:

N available in Year 1 = 24 t $ha^{-1}$ x 1.22 kg N $t^{-1}$ = 29 kg N $ha^{-1}$

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[1] Burton et al., 2003

[2] Hargreaves *et al.,* 2008

$P_2O_5$ available in Year 1 = 24 t $ha^{-1}$ x 1.08 kg $P_2O_5$ $t^{-1}$ = 26 kg $P_2O_5$ $ha^{-1}$

$K_2O$ available in Year 1 = 24 t $ha^{-1}$ x 1.11 kg $K_2O$ $t^{-1}$ = 27 kg $K_2O$ $ha^{-1}$

**3.** Estimation of the availability of nutrients to T3 in 2009 as contributed by treatment application rate FYW1.0 applied in 2008 to T1:

$^2$10% of N available = (1.215 % N / 100) x 1000 x 0.10 = 1.22 kg N $t^{-1}$

$^2$15% of $P_2O_5$ available = (0.718 % $P_2O_5$ / 100) x 1000 x 0.15 = 1.08 kg $P_2O_5$ $t^{-1}$

$^2$40% of $K_2O$ available = (0.278 % $K_2O$ /100) x 1000 x 0.40 = 1.11 kg $K_2O$ $t^{-1}$

Therefore:

N available in Year 2 = 24 t $ha^{-1}$ x 1.22 kg N $t^{-1}$ = 29 kg N $ha^{-1}$

$P_2O_5$ available in Year 2 = 24 t $ha^{-1}$ x 1.08 kg $P_2O_5$ $t^{-1}$ = 26 kg $P_2O_5$ $ha^{-1}$

$K_2O$ available in Year 2 = 24 t $ha^{-1}$ x 1.11 kg $K_2O$ $t^{-1}$ = 27 kg $K_2O$ $ha^{-1}$

**4.** Nutrient contributions from FYW compost treatment application rate, FYW1.0, as applied to T2 in 2009:

$^2$10% of N available = (1.61 % N / 100) x 1000 x 0.10 = 1.16 kg N $t^{-1}$

$^2$15% of $P_2O_5$ available = (0.53 % $P_2O_5$ / 100) x 1000 x 0.15 = 0.795 kg $P_2O_5$ $t^{-1}$

$^2$40% of $K_2O$ available = (0.17 % $K_2O$ /100) x 1000 x 0.40 = 0.68 kg $K_2O$ $t^{-1}$

Therefore:

N available in Year 1 = 24 t $ha^{-1}$ x 1.16 kg N $t^{-1}$ = 28 kg N $ha^{-1}$

$P_2O_5$ available in Year 1 = 24 t $ha^{-1}$ x 0.795 kg $P_2O_5$ $t^{-1}$ = 19 kg $P_2O_5$ $ha^{-1}$

$K_2O$ available in Year 1 = 24 t $ha^{-1}$ x 0.68 kg $K_2O$ $t^{-1}$ = 16 kg $K_2O$ $ha^{-1}$

**5.** Calculation to determine P and N removed in stover and grain separately:

Grain:

Total Nitrogen (TN) removed (kg $ha^{-1}$) = grain yield (kg $ha^{-1}$) x % N in grain sample

Total Phosphorus (TP) removed (kg $ha^{-1}$) = grain yield (kg $ha^{-1}$) x % P in grain sample

Stover:

TN removed (kg $ha^{-1}$) = stover dry matter (DM) yield (kg $ha^{-1}$) x % N in stover sample

TP removed (kg $ha^{-1}$) = stover DM yield (kg $ha^{-1}$) x % P in stover sample