EARTHWORM POPULATIONS IN AGRICULTURAL GREEN ROOFS AND THEIR INFLUENCE ON SOIL NITROGEN, GREATER TORONTO AREA

by

Caitlin Victoria Santos

H.B.Sc., McMaster University,

Hamilton, Ontario, Canada, 2013

A thesis

presented to Ryerson University

in partial fulfillment of the requirements

for the degree of

Master of Applied Science

in the program of

Environmental Applied Science and Management

Toronto, Ontario, Canada, 2018

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I authorize Ryerson University to lend this thesis to other institutions or individuals for the purpose of scholarly research.

I further authorize Ryerson University to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

I understand that my thesis may be made electronically available to the public.

Earthworm Populations in Agricultural Green Roofs and their Influence on Soil Nitrogen, Greater Toronto Area

Caitlin Victoria Santos

Master of Applied Science 2018

Environmental Applied Science and Management

Ryerson University

Abstract

Earthworm consumption and egestion of organic materials can increase bioavailable nitrogen in soils. Along with other benefits resulting from their burrowing activities, this process can increase soil fertility. This research investigated whether earthworms were present, and whether a relationship between earthworms and increased ammonium and nitrate levels was seen in the soils of the agricultural green roofs sampled in the greater Toronto area. Earthworms were found at several of the agricultural green roofs, but low soil moisture, low organic carbon, shallow depth, and compactness may have inhibited the establishment of earthworm populations in some soils. Results showed a statistically significant increase in levels of ammonium, but not in nitrate, with the increasing presence of earthworms. Findings indicate that some degree of increased bioavailable nitrogen benefits, resulting from earthworm presence, that are evident in conventional agricultural soils, can also be possible in agricultural green roofs, with attention to management of soil conditions that support earthworm populations.

Acknowledgements

I would like to use this opportunity to express my gratitude to my supervisors at Ryerson University, Dr. Michal Bardecki and Dr. Vadim Bostan. Without your continued support this research would not have been possible. I appreciate all the effort that you both put into this research to gain access the necessary materials, people, and laboratory access. The discussions about the research provided guidance, insights, and at time direction which helped me to produce this research. I really enjoyed all our thought processing and idea brainstorming discussions, which always ended hours later and off topic. I appreciate the patience from both of you and continued commitment.

I would also like to thank everyone who participated in this study. All the agricultural green roofs actors, I would like to thank you for your openness and interest in the research. Thank you for allowing me to study your agricultural green roofs to increase knowledge on the application. I enjoyed working with all of you. I would also like to thank those who I reached out to for professional advice on certain topics who helped with clarification.

My family and friends, whose support has been critical during this time. I know you are all eager for the successful completion of this research. I would like to thank you all for standing by me and all the patience and understanding. To Arlette Santos, John Santos, Sara Santos, my future husband Korey Tobias, Meghan Melo, Bincy Elamatha and everyone who is near and dear, a part of my loved ones past and present, who are cheering me on; for always being here in life with me, to seek it out and live it to the fullest.

Table of Contents

List of Tables

List of Figures

List of Appendices

1. Introduction

In most of North America, native earthworm species populations were eliminated by the Wisconsinan glaciations (Addison, 2009; Evers et al., 2012). Since then, introduction, establishment, and spread of European earthworm species have occurred (Addison, 2009; Evers et al., 2012). In Ontario, there are currently 17 species of introduced European earthworms, and two North American native species which were not native to Ontario (Addison, 2009; Evers et al., 2012). The spread of earthworms through their own migration is slow, with the through soil migration per year averaging 5 to 10 m (Addison, 2009; Pinder, 2013). Range expansion by natural migration through movement of earthworms through soil is therefore slow, and the main mechanisms of earthworm advancement into new areas are through anthropogenic or other methods of dispersal (Addison, 2009; Pinder 2013). Some dispersal methods include disposal of bait, cocoons carried down streams and deposited on banks, transportation in vehicles or in tire treads, agricultural use for soil fertility, earthworms carried and dropped by birds, transport with soil, and use in vermicomposting (Addison, 2009; Evers et al., 2012; Pinder, 2013).

In urban landscapes, most areas are paved over, leaving a lack of green space. A more recent effort to bring green space into cities is through green roofs (Peck & Kuhn, 2003). Here, there can be a simple, shallow growing medium with grasses and other stress-tolerant ground cover plants for the main purpose of energy savings or water retention (Peck & Kuhn, 2003). There can also be green roofs with deeper growing mediums to support gardens or agricultural plants (Peck & Kuhn, 2003). The depths of green roof soils are shallower than those found naturally due to weight considerations. Extra weight requires extra support and building materials raising capital costs of such projects (Peck & Kuhn, 2003). The green roofs are also more isolated from other environments than conventional gardens. This leads to the questions of whether earthworms are present in the soils on green roofs, either brought up to green roofs during construction or subsequently introduced into green roof soils by an alternative dispersal mechanism, and whether they can survive in these soils. If green roofs are meant to host agricultural plants, there may be a benefit to having earthworm populations present in the green roofs soils as they have been known to increase soil fertility by increasing the availability of nitrogen, which is a limiting nutrient for plant growth, and manipulating soil structure (Scheu & Parkinson, 1994; Scheu et. al., 1999; Kladivko, 2001; Buffam & Mitchell, 2015). Agricultural crops require additional water and nutrient inputs compared to the plants in the more common, extensive green roofs. The application of these additional nutrients needs to be closely managed. This is so that the plants needs are met appropriately to allow for adequate growth, but not exceeded which could result in negative consequences such as increased runoff and increased nutrient pollution in runoff.

There is a growth in the number of green roofs being constructed in accordance with the new bylaw in the city of Toronto, the *Green Roof bylaw, Toronto Municipal Code Chapter 492, Green Roofs* (City of Toronto, 2009). The bylaw requires that all buildings constructed after January 30th, 2010, have between 20 percent to 60 percent of green roof coverage on their roofs based on the square footage of the building (City of Toronto, 2009). The bylaw includes some standards or references to standards on the requirements of the green roof, but does make any reference to agriculture on green roofs either as a requirement or a guideline for agricultural green roof applications (City of Toronto, 2009). Any choice to invest in agricultural green roof applications and beyond the bylaw standards how to design, maintain, and carry out the application would be a decision left to the building or property owners, occupants, or construction companies. There are various uses for green roofs including aesthetic gardens and small scale agricultural gardens. Nitrogen can be a limiting factor to growth, and earthworms can increase the production of bioavailable nitrogen enhancing the possible success of plant growth (Costella & Lamberti, 2008; Costella & Lamberti, 2009; Costella, 2010). Earthworms can also increase water infiltration in soils, soil aeration, and soil mixing which can improve plant growth (Edwards et al., 1989; Edwards et al., 1990; Scheu & Parkinson, 1994; Scheu et. al., 1999; Shipitalo et al., 2004; Addison, 2009; Kladivko, 2001; Evers et al., 2012). The survey of earthworm populations on green roofs will give an idea of the status of earthworm presence and ability to survive in these soils. A survey of earthworm populations and nitrogen species in agricultural green roofs will give an idea of their status and their relationship within agricultural green roof soils. Measurements of nitrogen species and information from the people who manage the green roofs will provide further insight into the status of management strategies on green roofs. Increased information about the scenarios, and actors involved in the development and management of agricultural green roofs can result in greater knowledge on the subject so more appropriate decisions can be made. This will increase the effectiveness of plant growth and yeilds of agricultural green roofs. This is important because currently green roofs are seen as an environmental benefit in urban areas. There are high capital costs involved with green roofs and additional maintenance costs over time, all increasing with the intensiveness of the green roof. Agricultural green roofs are more on the intensive side of what commonly exists with green roof applications. If strategies fail to be productive or produce increasingly polluted runoff as seen in several studies that will be presented here, then this is reason for disinvestment in agricultural green roofs. The future success of agricultural green roofs, therefore, depends on increasing the knowledge base specific to green roofs and beneficial strategies to help support the success of current agricultural green roof applications.

The objectives of this study were to explore what earthworm populations are present in agricultural green roofs soils. The amounts and of nitrogen species, including ammonium, and nitrate in these agricultural green roof soils was analyzed. Possible effects of earthworm presence on nitrogen species measurements was examined. The possible effects of different agricultural plants and practices and insight into agricultural green roof operations within the greater Toronto area was also considered in analysis for the selected sites.

To fulfill the objectives of this study, several methods were employed. There will be a field component to collect earthworm and soil samples. This will be followed by a lab component to analyze the earthworm and soil samples for earthworm identification, and soil characteristics; nitrogen species, pH, water content, organic carbon content, and clay content. An interview component will help to provide insight into the agricultural green roofs examined and agricultural green roofs in general. An analysis component will involve statistical analysis of measurements and additional literature review to explore and discuss the results.

2. Literature Review

This literature review will begin with an overview of earthworms in their soil habitats. Nitrogen cycling in soils will be overviewed. The influences earthworms have on nitrogen cycling in soils and how this is made use of in agriculture will be presented. A look at green roofs, what they are, and studies of macroinvertebrates and nitrogen dynamics on green roofs that exist in the literature currently will be presented.

2.1. Earthworms

Based on their burrowing behaviours there are three main ecological groups that are used to classify earthworms (Evers et al., 2012). The different functional groups of earthworms can be found at different depths in the soils they inhabit (Kladivko, 2001). Epigeic earthworms are found in the litter layers, endogeic earthworms are found within the top 30 cm of the soil, and anecic earthworms create burrows from the surface of the soil to depths of approximately 1 to 2 metres below the soil surface (Kladivko, 2001). Epigeic earthworms burrow horizontally in the surface litter layers (Kladivko, 2001; Evers et al., 2012). They consume leaf litter, preferentially with higher organic content (Evers et al., 2012). Endogeic earthworms can be located in the soils just below the soil surface and they burrow horizontally (Evers et al., 2012). These species consume smaller soil particles and their burrowing and feeding behaviours can lead to organic matter becoming incorporated into the surficial layers of mineral soils, and mineral soils in upper soil horizons (Evers et al., 2012). Anecic earthworms burrow vertically, from the soil’s surface to the deeper mineral layers (Addison, 2009; Evers et al., 2012). They consume partially decomposed organic matter and leaf litter, which is carried from the surface to deeper soil layers, including the mineral layer, through the earthworm’s burrows; soils from the mineral layer are carried to the upper horizons in the same fashion creating a mixing effect in the soils (Addison, 2009; Evers et al., 2012). Each species of earthworms has specific soil preferences but generally they can inhabit soils with strongly acidic pH values around 4 and higher, and soil moisture contents can not be too low and dry, or too high and flooded (Auerswald et al., 1996; Muys & Granval, 1997; Römbke et al., 2005)

2.2. Nitrogen Dynamics in Soils and the Influences of Earthworms

Nitrogen cycling involves several reactions which at times require opposing conditions. Nitrogen gas (N_2) in the atmosphere enters the soil through nitrogen fixation which can take place through lighting strikes or, most commonly, through the biological nitrogen fixation (BNF) of nitrogen gas by microbes to organically bound nitrogen or ammonium (NH_4^+) (Galloway et al., 1995; Galloway et al., 2003; Buffam & Mitchell, 2015). Presently, anthropogenic nitrogen fixation of nitrogen gas into reactive nitrogen species, mainly ammonia (NH_3), is an additional and large route for the introduction of nitrogen into soils (Galloway et al., 1995; Galloway et al., 2003). The microbial breakdown of nitrogen in soils involves nitrogen mineralization, the breakdown of organically bound nitrogen to ammonium (NH_4^+), followed by nitrification, the transformation of ammonium to nitrate (NO_3^-), and ending with denitrification, the transformation of nitrate to gaseous nitrogen species (N_2 and NO_x) which removes nitrogen from the soil (Mikkelson & Vesho, 2000; Pinder, 2013; Buffam & Mitchell, 2015). Ammonium and nitrate are bioavailable forms of nitrogen which can readily be taken up by plants, and incorporated into the plant's organic biomass (Buffam & Mitchell, 2015). Nitrification is an aerobic process whereas the subsequent denitrification is an anaerobic process. Increased water in soils, and increased compaction of soils are two common conditions that both lead to reduced space and ability for oxygen to diffuse into the soil, and this favours anaerobic processes such as denitrification (Smith & Tiedje, 1979; Asady & Smucker, 1989; Drew, 1990; Dobbie et al., 1999; Dobbie & Smith, 2001; Costella & Lamberti, 2008; Beare et al., 2009; Balaine et al., 2013). This leads to the transformation of nitrate to gaseous nitrogen species being a dominant reaction (Smith & Tiedje, 1979; Asady & Smucker, 1989; Drew, 1990; Dobbie et al., 1999; Dobbie & Smith, 2001; Costella & Lamberti, 2008; Beare et al., 2009; Balaine et al., 2013). However, earthworm burrowing by endogeic and anecic species increases the permeability of soils and facilitates the transport of oxygen (O_2) into soils (House & Parmelee, 1985; Joschko et al., 1989; Parkin & Berry, 1999; Costella & Lamberti, 2008). This creates more oxic conditions, and subsequently alters the redox potential increasing the potential for aerobic reactions (House & Parmelee, 1985; Costella & Lamberti, 2008). This increases the potential for nitrification and the conversion of ammonium into nitrate (Edwards et al., 1989; Parkin & Berry, 1999; Costella & Lamberti, 2008). On the other hand, higher soil moisture creates anoxic conditions necessary for anaerobic denitrification; earthworms can also influence water infiltration and therefore soil moisture content (Edwards et al., 1989; Edwards et al., 1990; Parkin & Berry, 1999; Joschko et al., 1989; Mikkelson & Vesho, 2000). Pinder (2013) found a positive relationship between rates of denitrification in riparian soils and soil moisture and respiration further supporting this concept. Conditions due to earthworm activities can not only alter the redox potential of reactions in soils, but this can also increase populations of nitrifying and denitrifying organisms by providing favourable conditions for their growth (Parkin & Berry, 1999). This would lead to additional increases in nitrification or denitrification rates depending on the aerobic or anaerobic state of the soil at the time (Parkin & Berry, 1999).

Experiments by Costello and Lamberti (2008) examined nitrogen dynamics in riparian zones in relation to invading earthworms. The experiments by Costella and Lamberti (2008) found alterations in nitrogen dynamics between conditions. With an increasing earthworm biomass there was an increase in total nitrogen (TN) present in leachate (Costella & Lamberti, 2008). The majority of nitrogen species present in the leachate were in the form of nitrate and a small percentage were in the form of ammonium (Costella & Lamberti, 2008). A similar result was found by Scheu and Parkinson (1994), who saw an increased amount of nitrogen being leached, mainly in the form of nitrate, from soils when earthworms were added. Costella and Lamberti (2008) saw that an increasing earthworm biomass was positively correlated with increasing amounts of ammonium and nitrate in leachate, with amounts of nitrate also increasing over time. Earthworms excrete nitrogen, primarily in the form of ammonium (Costella & Lamberti, 2008). When *Dendrobaena octaedra* and *Lumbricus terrestris* were fed various species of leaves, a carbon limitation was observed for the growth of earthworms (Costella, 2010). There was a high amount of nitrogen present in casts and waste products, which can drive the increase in ammonium seen with increasing earthworm biomass (Costella & Lamberti, 2008; Costella, 2010). The amount of ammonium did not increase with time; however the amount of nitrate did (Costella & Lamberti, 2008). This buildup of nitrate can be due to the increasing favourable conditions for aerobic processes, such as nitrification of ammonium to nitrate, associated with earthworm activity (Costella & Lamberti, 2008). This would keep the increasing inputs of ammonium under control by conversion to nitrate, and cause an accumulation of nitrate due to an increase in nitrification and decrease in denitrification following a change in redox potentials (Costella & Lamberti, 2008). The soils in and around earthworm burrows cultivate these conditions and situations (Costella & Lamberti, 2008).

The movement of nitrogen from soils is influenced by earthworms. In field experiments by Costella and Lamberti (2009), it was found that denitrification of nitrate into gaseous nitrogen was the dominant form of nitrogen removal from soils. In this circumstance, the rainfall was approximately half of the usual rainfall for that time period (Costella & Lamberti, 2009). This decreased drainage and flushing of nitrogen, in the form of ammonium or nitrate, out of the soils through movement with infiltrating water (Costella & Lamberti, 2009). It also increased the hydraulic retention time of the soils increasing the contact time and probability of microbial denitrification (Costella & Lamberti, 2009). Between three treatments – control (no burrows or earthworms), burrows (manually created burrows and no earthworms), and earthworms (earthworm created burrows and earthworms) – the net nitrogen mineralization rate and the net nitrification rate were not seen to differ between either of the manipulation treatments (burrows or earthworms) compared to the control treatment (Costella & Lamberti, 2009). The denitrification rate was unchanged between the control and burrow conditions; however, it was approximately 400% greater in the earthworm condition compared to the control condition (Costella & Lamberti, 2009). This shows that burrows alone do not lead to a flux in nitrogen dynamics, but that other earthworm activities such as feeding, egestion, and mucus secretion, are also involved in the nitrogen flux associated with earthworms (Costella & Lamberti, 2009). Similar results were found by Pinder (2013), where overall earthworm biomass was positively associated with denitrifaction. Mass balance suggests that the unaccounted for input of nitrate necessary to raise denitrification rates were provided for by nitrification, since earthworms do not egest nitrate (Costella & Lamberti, 2009). Gross nitrification therefore would have had to increase to a similar rate as denitrification to provide the necessary reactants for the denitrification rates found (Costella & Lamberti, 2009). Here, denitrification would have counterbalanced the increased nitrification, leading to no net change in nitrification between the earthworms and other treatments (Costella & Lamberti, 2009). Overall, whether or not the flux of nitrogen out of soils occurs through denitrification, surface or subsurface flow depends on the soil characteristics and amount of rainfall for drainage (Costella & Lamberti, 2009). The amounts of nitrogen in and moving from soils can be affected by the presence of earthworms, and, as will be discussed further, the soil characteristics that determine whether nitrogen goes through denitrification or is drained from soils can also be affected by the presence of earthworms.

Adsorption of nitrogen species to soil particles can also increase the retention of nitrogen in soils and reduce drainage and movement of nitrogen. Ammonium has a higher adsorption potential to soils than nitrate (Kothawala & Moore, 2009). The adsorption of ammonium to mineral soils increases with clay content and pH (Kothawala & Moore, 2009). Adsorption to mineral soils by nitrate is weak and does not exhibit the same increases with changing conditions as with ammonium nitrogen species (Kothawala & Moore, 2009). Mixing of mineral soils into upper soil horizons by endogeic and anecic earthworms may possibly increase this effect by supplying more mineral soils where earthworm activity occurs (Scheu & Parkinson, 1994; Addison, 2009; Evers et al., 2012). This enhanced retention of ammonium can extend the chance of the reduction of the ammonium to nitrate through microbial nitrification. Ammonium and nitrate are very water soluble and therefore can be carried with infiltrating water into subsurface soils readily (Turtola & Paajanen, 1995). Nitrate can be carried with water through soil especially easily because the movement is not impeded by adsorption to soils (Kothawala & Moore, 2009; Turtola & Paajanen, 1995).

Improved water infiltration and drainage of soils has been seen to increase nitrogen leaching (Turtola & Paajanen, 1995). Earthworms have been studied to have several effects on infiltration capabilities involving soil texture and porosity. Most noted is the effect of anecic earthworms. Anecic earthworm burrows increase water infiltration into soils through their large vertical burrows (Shipitalo et al., 2004). This effect occurs during dry and wet conditions (Shipitalo et al., 2004). Additional effects earthworms have on water infiltration into soils involve the level of compaction and the production of castings as a result of their activities (Blanchart et al., 2004). Endogeic earthworms, which burrow horizontally, have different effects on water infiltration into soils depending on the species (Blanchart et al., 2004). There are decompacting or compacting endogeic earthworm species (Blanchart et al., 2004). Smaller, decompacting, endogeic earthworms would reduce the bulk density of soils, increasing soil porosity and hence increase water infiltration to an extent similar to what would be seen in soils without earthworms (Blanchart et al., 2004; Hoorman et al., 2011). These species also produce smaller, granular casts at the soil surface which are fragile (Blanchart et al., 2004). These smaller casts disperse easily during wetting events which can lead to an even distribution of small, granular casts at the soil surface (Blanchart et al., 2004; Morin, 1993). This increases the clogging of pores and positively contributes to surface sealing which ultimately contributes to the formation of a surface crust if subsequent and adequate drying events occur (Blanchart et al., 2004; Morin, 1993; Zejun et al., 2002). Surface crusting increases the soil bulk density and hence reduces water infiltration into soils (Morin, 1993; Zejun et al., 2002). Larger, compacting, endogeic earthworms increase the bulk density of soils, decreasing soil porosity and hence decreasing water infiltration (Blanchart et al., 2004; Hoorman et al., 2011). These species also produce larger globular casts which are coagulated or flattened and are relatively stable compared to the smaller, granular casts produced by decompacting species (Blanchart et al., 2004). Freshly egested casts still have a high water content and can be washed away with wetting events (Blanchart et al., 2004). Casts need to dry before they increase in water stability, increasing their longevity through wetting events (Blanchart et al., 2004). Casts have an increased bulk density compared to soils and hence decrease infiltration capability, which increases with the increasing stability of casts (Blanchart et al., 2004). The higher the deposition of casts in anecic earthworm burrows, the increased clogging and hence decreased improvement in infiltration associated with these vertical burrows if subsequent cast drying occurs (Blanchart et al., 2004). Whether the soils become decompacted or compacted by earthworms can lead to root development to spread to a greater or lesser volume of soil respectively (Syers & Springett, 1984). Water infiltration effected by the level of compaction of soils influenced by earthworms can help improve or detract from soil moisture levels needed for plant growth.

2.3. Earthworms and Agriculture

Soil fertility and structure can be improved through earthworm activity. Earthworm activities lead to the nutrient mobilization of nitrogen, improving its accessibility to plants (Scheu & Parkinson, 1994; Scheu et. al., 1999). This has been associated to the increased plant growth seen when earthworms are present (Scheu & Parkinson, 1994; Scheu et. al., 1999). This is especially true if the plant is not a legume, most of which have nitrogen fixing bacteria in their roots, and therefore already have access to adequate amounts of nitrogen (Scheu et. al., 1999). Earthworm casts are a source of nutrients for plants (Chaoui et. al., 2003). The relative stability of earthworm casts compared to compost or fertilizers allows for a slow release of nitrogen which was seen to coincide more closely to plants nutrient needs (Chaoui et. al., 2003). This slow release of nitrogen from casts prevents salinity intensification associated with the same amount of nitrogen applied through non-vermicompost or fertilizer, and reduces the potential of salinity stress on the plants (Chaoui et. al., 2003). A slower release of nitrogen could also lead to less nitrogen lost through runoff and drainage (Chaoui et. al., 2003). The mixing of soils and movement of soils close to the surface to soil layers further down moves nitrogen deeper into the soils as well, which can reduce the surface runoff nitrogen and redistribute the nutrients (Syers & Springett, 1984). The increased soil porosity attained through earthworm burrowing, the associated increase in soil aeration and moisture content, and soil mixing provided by earthworms are all advantageous improvements in agricultural soils (Kladivko, 2001). Earthworm populations in soils can be incorporated as part of agricultural regimes as alternatives to other options to increase the environmental friendliness of the growing practices used (Scheu, 2003).

2.4. Green Roofs

This section will introduce the concept of a green roof. Following this there will be a summary of knowledge gathered from the literature about macroinvertebrates in green roofs, and nitrogen dynamics in green roofs.

2.4.1. Green Roof Description

Green roof is an ambiguous term used to describe a variety of gardening activities occurring on roof tops. Here, green roofs are roof tops that are “designed to support vegetation” (Dvorak & Volder, 2010; Whittinghill & Rowe, 2012). Green roofs, as considered here, will include features such as a root barrier, drainage layer, filter layer, growing substrate, and vegetation (Whittinghill & Rowe, 2012). This can still be seen as a broad definition, but the further details of the types of designs involved in an attempt to support vegetation on a roof top, convey an additional level of sophistication to a green roof compared to potted plants on roof tops, which are not considered green roofs here. Green roofs are an application of urban agriculture, which is all the activities involved in the production and distribution of agriculture, including livestock, within urban areas (Van Veenhuizen & Danso, 2007). The *Green Roof* *bylaw, Toronto Municipal Code Chapter 492, Green Roofs* does not have requirements for agricultural green roofs to be constructed or guidelines for agricultural green roofs (City of Toronto, 2009). So growing agriculture on green roofs would be an initiative taken on by the building or property owners, occupants, or construction companies. Urban agriculture takes place in cities all over the world in many forms including agricultural green roofs. In Toronto, there is a Toronto Food Policy Council (TFPC), which is a subcommittee of the Toronto Board of Health (Kaethler, 2006; Blay-Palmer, 2009; Toronto Food Policy Council, n.d.). The TFCP acts as consultants on food policy issues with activities include providing support for urban agriculture by working with the municipality, community, and organizations to advance urban agriculture through advocacy, awareness, project planning support, and research (Kaethler, 2006; Blay-Palmer, 2009; Toronto Food Policy Council, n.d.). The Toronto Community Gardens program, the Toronto Community Gardens network, and non-profit organizations in Toronto provide various support for urban agriculture projects, including project technical support, education on agriculture, and funding opportunities (Kaethler, 2006; Toronto Urban Growers, 2017). Along with many other organizations and institutions, the TFCP created a report entitled the GrowTO Urban Agriculture Action Plan, which was later adopted by the City of Toronto as the Toronto Agriculture Program (Toronto Food Policy Council, 2012; City of Toronto, 2013; Toronto Food Policy Council, n.d.). The GrowTO Urban Agriculture Plan, adopted as the Toronto Agriculture Program provides information on opportunities and to take to increase the scale of urban agriculture in Toronto including promoting green roof agriculture as a large area for growth and potential benefits (Toronto Food Policy Council 2012; City of Toronto, 2013; Toronto Food Policy Council, n.d.). In preparation for this study an internet search of green roofs that grow agricultural crops in the greater Toronto area was carried out to determine if there were applications available to study. There are 15 known applications of agricultural green roofs in the greater Toronto area found through this search at the time of this study, and it is possible that there are more applications not documented or reported on that exist in the city.

There are different types of green roofs, and depending on the use of the green roof, they are designed differently. The main types of green roofs fit into either the intensive or extensive category, differentiated mainly by the growing substrate depth, and the vegetation (Peck & Kuhn, 2003; Oberndorfer et al., 2007; Whittinghill & Rowe, 2012; Buffam & Mitchell, 2015). Extensive green roofs are shallower than intensive green roofs with approximately less than 15 cm and greater than 15 cm of growing substrate respectively (Peck & Kuhn, 2003; Oberndorfer et al., 2007; Whittinghill & Rowe, 2012). The shallower substrate depths in extensive green roofs decrease the variety and amount of vegetation they can support (Oberndorfer et al., 2007; Buffam & Mitchell, 2015). This, in addition to the increase in extreme conditions on roof tops such as temperatures, moisture fluctuations, wind and light intensity, lead to extensive green roofs applications with plants that display stress tolerance, commonly succulents, such as sedums, and mosses (Oberndorfer et al., 2007; Buffam & Mitchell, 2015). The deeper the substrates the greater the variety of vegetation that can be supported (Oberndorfer et al., 2007; Buffam & Mitchell, 2015). Herbaceous plants include vegetables, and for growth they require deeper growing substrate for possible increased support, water retention, and insulation, and increased inputs such as water, and nutrients, compared to the stress tolerant plants seen commonly in extensive green roofs (Dunnett & Nolan, 2002; Getter & Rowe, 2006; Rowe et al., 2006; Whittinghill et al., 2013). The intensive green roofs which are deeper, more likely to have soil mediums, and have the ability to host a greater biomass and a more biodiverse range of plant species, are more likely to provide habitable soils for earthworms than extensive green roofs (Peck & Kuhn, 2003; Brenneisen, 2006; Schrader & Boning, 2006; Buffam & Mitchell, 2015).

2.4.2. Macroinvertebrates in Green Roofs

Some studies have examined other macroinvertebrates populations in green roofs. In Halifax, Nova Scotia, Canada, older, intensive green roofs were found to host a diversity and abundance of insects, comparable to habitats on the ground surrounding the examined green roofs, with no statistically significant difference between the two types of habitats (MacIvor & Lundholm, 2011). In France, increased abundance and diversity of arthropods, beetles and hymenopterans were seen with increased complexity and diversity of vegetation present in the green roofs examined (Madre et al., 2013). A great interest in pollinator bees exists, and research on these macroinvertebrates has been studied separately. Pollinator bees have been found with lower diversity and amounts in greens roofs than in habitats surrounding buildings, and nearby natural prairie habitats (Tonietto et al., 2011; Ksiazek et al., 2012). An increase in vegetation, specifically flowering plants increased the amounts of pollinator bees found (Ksiazek et al., 2012). Green roofs have been seen to provide a habitat able to support macroinvertebrates.

2.4.3. Nitrogen Dynamics in Green Roofs

Most studies which provide insight into nitrogen dynamics specifically related to green roofs are in the form of runoff quality assessments. These studies measure the concentration and/or amounts of nitrogen species in the runoff from different green roof applications. These measurements have been compared to water samples from runoff from some form of control roof, some irrigation source such as precipitation, or the different green roof applications. Most of these studies report on whether results purport that the green roofs are a source or sink for nitrogen. To formulate some ideas of nitrogen dynamics in green roofs, as investigated so far, a sample and variety of these studies is summarized here.

In Sweden, runoff water quality of extensive green roofs with sedum and moss vegetation was analyzed against runoff of control, non-vegetated roofs (Berndtsson et al., 2006). The green roofs were seen to be sinks for nitrogen, with the highest amounts for nitrate followed by ammonium and total nitrogen (Berndtsson et al., 2006). Total nitrogen had highest leaching of all forms of nitrogen measured (Berndtsson et al., 2006). There was an increase in total nitrogen leaching seen on newer roofs and after fertilization events (Berndtsson et al., 2006). The increased total nitrogen in runoff seen could be due to increased organic inputs, including organic nitrogen, to soils that comes with fertilization and with high amounts of fertilizer in the initial substrate installed (Berndtsson et al., 2006).

A follow up and addition to this study was completed looking at one of the same extensive green roofs in the Berndtsson study in Sweden (2006), and an intensive green roof in Japan. In Sweden, runoff water quality, for the same extensive green roofs with sedum and moss vegetation were sampled two years later, when no additional fertilization had occurred for approximately 3 years (Berndtsson et al., 2009). In Japan, runoff quality of an intensive green roof with upwards of 70 different plant species was analyzed (Berndtsson et al., 2009). Runoff for the green roofs was compared to runoff from urban surfaces as analyzed in literature, and to precipitation samples collected (Berndtsson et al., 2009). Both the extensive and intensive green roofs were sinks for nitrate and ammonium, and the intensive green roof was a sink for total nitrogen whereas the extensive green roof was not (Berndtsson et al., 2009). More often, the total nitrogen concentrations in runoff for the extensive green roof were comparable to urban runoff total nitrogen concentrations found in literature, whereas the intensive green roof had lower total nitrogen concentrations than what is found in literature for urban runoff (Berndtsson et al., 2009). Larger plants in intensive green roofs may increase the uptake of inorganic nitrogen and retain it in organic form with a greater capacity than smaller plants in extensive green roofs, and hence contribute to the sink of total nitrogen observed for the intensive green roof (Berndtsson et al., 2009).

In Toronto, Canada, runoff water quality of an extensive green roof with wildflower vegetation was analyzed against a control, modified bitumen-shingled, non-vegetated section of the same roof (Van Seters et al., 2009). The study took place overall several growing seasons, with no winter monitoring: May 2003 to November 2003; June 2004 to November 2004; April 2005 to August 2005 (Van Seters et al., 2009). Nitrate, nitrite and ammonia concentrations were lower in the green roof runoff compared to the non-vegetated roof runoff; however, total Kjeldahl nitrogen (TKN) in the green roof runoff was higher than in the non-vegetated roof runoff (Van Seters et al., 2009). The loading in runoff of all nitrogen species measured, including TKN, was higher for the conventional, non-vegetated roof than the green roof (Van Seters et al., 2009).

In Texas, growth medium measurements and runoff water quality for an experimental, extensive, modular green roof, vegetated with either *Sedum kamtschaticum*, *Delosperma cooperi* or *Talinum calycinum* (low maintenance, relatively tolerant plants), and non-vegetated green roof module plots were analyzed (Aitkenhead-Peterson et al., 2011). Looking at the growth media after six months compared to initial conditions, several observations were noted (Aitkenhead-Peterson et al., 2011). There was a decrease in the amount of dissolved organic nitrogen (DON), ammonium, and nitrate in all vegetated and non-vegetated treatments compared to the initial substrate (Aitkenhead-Peterson et al., 2011). Nitrate, specifically, showed a statistically significant increase in the percent reduction in the growing medium in the *Delosperma cooperi* and the *Talinum calycinum* vegetated plots, compared to the non-vegetated and the *Sedum kamtschaticum* vegetated plot (Aitkenhead-Peterson et al., 2011). This significant difference in nitrate loss was attributed to greater plant uptake of nitrate by *Delosperma cooperi* and *Talinum calycinum*, as opposed to increased denitrification, since conditions to support the level of denitrification necessary for this result were not observed (Aitkenhead-Peterson et al., 2011).

Measurements from leachate samples in the different experimental conditions, the conventional rooftop runoff, which consisted of polyurethane foam that had an exposed granular topcoat, precipitation, and tap water used for irrigation were all compared (Aitkenhead-Peterson et al., 2011). Nitrate concentrations in leachate in the *Delosperma cooperi* and the *Talinum calycinum* condition did not show a statistically significant difference from the conventional roof runoff, precipitation and tap water, but did show a statistically significant reduction from the non-vegetated and the *Sedum kamtschaticum* condition (Aitkenhead-Peterson et al., 2011). Ammonium concentrations in leachate did not show a statistically significant difference between conditions, except in the case of the tap water which had a statistically significantly lower concentration than the other samples (Aitkenhead-Peterson et al., 2011). Dissolved organic nitrogen (DON) concentrations in leachate had a statistically significantly higher amount in vegetated and non-vegetated green roof plots compared to conventional roof runoff, precipitation and tap water (Aitkenhead-Peterson et al., 2011). Some differences seen between the *Sedum kamtschaticum* and the other vegetation varieties could have been due to the death of about half of the plants in this condition, which could have increased pools of nitrogen and decreased uptake and retention of nitrogen in organic form within vegetation (Aitkenhead-Peterson et al., 2011). The experimental green roof setting was not determined to be a nitrogen sink as with other experiments, and it was mentioned this is possibly due to inputs from the growing substrate since there was lower nitrogen deposition from the atmosphere in Texas compared to other experiments in Sweden and Japan (Berndtsson et al., 2006; Berndtsson et al., 2009; Aitkenhead-Peterson et al., 2011). Health and capability of the vegetation involved was also mentioned as a factor involved in whether or not the green roof acted as a sink for nitrogen (Aitkenhead-Peterson et al., 2011).

In North Carolina, runoff water quality of extensive green roofs with succulent and sedums vegetation were analyzed against a control, gravel ballast or non-ballast, non-vegetated section of roof on the same rooftops (Hathaway et al., 2008). The first two years of the green roof's existence was measured, and there was a high initial percentage of organic material in substrate, 15% cow manure (Hathaway et al., 2008). Green roof runoff had statistically higher concentrations of total nitrogen than rainfall but not control roofs (Hathaway et al., 2008). Differences between mass loadings of total nitrogen in different outflows (rainfall, green roof and control roof) were not significant, with all conditions displaying the largest loadings at various times, varying based on the amount of rainfall, outflow and the amount of total nitrogen in the sources (Hathaway et al., 2008). There may be less total nitrogen leached from the green roof with time as the green roofs were highly concentrated with nutrients at time of study, contributing to these green roofs acting as nitrogen sources (Hathaway et al., 2008).

In Norfolk, Virginia, experimental, extensive vegetated green roof plots with sedums, experimental gravel roof plots, a full-scale extensive green roof vegetated with sedums and an adjacent gravel roof were analyzed (Malcolm et al., 2014). Both experimental and full-scale green roofs used the same vegetated pods and sampling was conducted for about two years beginning after the construction of the green roof (Malcolm et al., 2014). Total nitrogen concentrations in runoff for the experimental plots were higher in the green roof plots than the gravel roof plots, and both plots had higher total nitrogen concentrations than the precipitation (Malcolm et al., 2014). When analyzed, a high percentage of the nitrogen in runoff was in the form of nitrate (Malcolm et al., 2014). The concentration of total nitrogen in runoff from the green roof plots decreased over time which was possibly due to fertilizer in the vegetated pods planted in this condition which contained 15 percent compost, no additional fertilizer was added (Malcolm et al., 2014). In the full-scale conditions, the green roof had a higher concentration of total nitrogen in runoff than the gravel roof runoff and precipitation (Malcolm et al., 2014). This may also be due to high initial amounts of fertilizer in the vegetated pods (Malcolm et al., 2014).

In Sweden, runoff water quality of extensive green experimental plots with green roof substrate, a 2-year-old green roof pre-vegetated mat, and vegetated green roof with sedums which were grown from shoots was analyzed (Emilsson et al., 2007). This was done in a controlled experiment within a greenhouse (Emilsson et al., 2007). A controlled release fertilizer was compared to a conventional, easily dissolved fertilizer (Emilsson et al., 2007). A greater concentration and amount of nitrogen was released in runoff with easily dissolved fertilizers compared to controlled release fertilizers (Emilsson et al., 2007). The pattern of runoff concentrations for all nitrogen species generally began with a peak in concentration which was immediate for ammonium and delayed for nitrate and total nitrogen, followed by an exponential decline overtime for ammonium, and gradual decline overtime for total nitrogen and nitrate (Emilsson et al., 2007). This scenario for ammonium and nitrate was possible due to favourable conditions for nitrification, observed during the experiment, decreasing amounts of ammonium while increasing amounts of nitrate (Emilsson et al., 2007). The vegetated mats and the sedum plots reduced the concentration of ammonium and total nitrogen in runoff compared to the unvegetated substrate, and the vegetated mat reduced nitrate concentration in runoff compared to the sedum and unvegetated substrate plots (Emilsson et al., 2007). The vegetated mats also showed lower amounts of total nitrogen, nitrate, and ammonium (Emilsson et al., 2007).

At Michigan State University's Horticultural Teaching and Research Center, in East Lansing, Michigan, runoff water quality was analyzed for an extensive green roof which used green roof platforms, and had three vegetated conditions with either sedums, a native prairie mixture, or a vegetable and herb mixture (Whittinghill et al., 2015). Nitrate measurements were taken after the setup of the green roof platforms, after the first fertilization and after the second fertilization (Whittinghill et al., 2015). There was no statistically significant difference between the nitrate concentrations in runoff between vegetation conditions (Whittinghill et al., 2015). The nitrate concentrations in runoff decreased over time for all vegetated conditions (Whittinghill et al., 2015). Although the vegetable and herb condition was the only scenario with additional fertilization, the amounts of nitrogen were below the recommendations for the vegetables and herbs present (Whittinghill et al., 2015). The additional nitrogen was possibly taken up by plants not allowing for a statistically significant increase in nitrate in the runoff from the vegetable and herb condition compared to the other two vegetated conditions (Whittinghill et al., 2015).

The results from the experiments are variable. Some experiments present findings for green roofs acting as sinks for nitrogen or better options than conventional or control roof tops (Berndtsson et al., 2006; Berndtsson et al., 2009; Van Seters et al., 2009). Some results show no statistical distinction either way (Berndtsson et al., 2009). And some found green roofs acting as sources for nitrogen (Hathaway et al., 2008; Aitkenhead-Peterson et al., 2011; Malcolm et al., 2014). Some studies looked at green roofs with different features. Differences were found between and extensive compared to an intensive green roof (Berndtsson et al., 2009), and between different plants and vegetation conditions (Emilsson et al., 2007; Aitkenhead-Peterson et al., 2011). Although no differences were found between the different plants in the study by Whittinghill et al. (2015), it can be hypothesized that with increased amounts of nitrogen inputs to all conditions, differences in the plant capabilities would be presented. Factors involved in variations among studies include surrounding conditions such as climate and pollution, the specifics of the green roof design such as amount and type of substrate and vegetation, and the accompanying features including filters and drainage layer designs, fertilization type and amount, and the age of the green roofs studied (Berndtsson et al., 2006; Van Seters et al., 2009). Over time, the age and the maintenance regimes carried out on the green roofs add to the differences seen (Berndtsson et al., 2006; Emilsson et al., 2007; Malcolm et al., 2014; Whittinghill et al., 2015). These factors which play a role in determining what inputs go into the green roof, how the green roof functions, and productivity of the vegetation, all can transfer to differences in what is seen in the outflows from the green roof.

The use of easily soluble fertilizers would not be recommended based on these studies, as they can release nitrogen in amounts that exceed plant's needs in the beginning resulting in high leaching of nitrogen (Berndtsson et al., 2006; Emilsson et al., 2007). Instead, controlled release fertilizers slowly release nitrogen over time which can more appropriately meet plants needs while reducing the concentration and amount of nitrogen leached into runoff from green roofs (Emilsson et al., 2007). Earthworm casting have been seen to allow for this slow release of nutrients to more closely meet plants needs and could be an option which merits further investigation (Chaoui et. al., 2003).

2.5. Hypotheses

Considering the literature, it is expected that agricultural green roof soils where earthworms are found will have higher amounts of bioavailable nitrogen than soils where earthworms are not present. This will be measured in the forms of ammonium and nitrate. The deepest burrowing earthworms, anecic earthworms, are not expected to be found because the soil depths they inhabit are not expected to be found on the agricultural green roofs. Any earthworms found are expected to be epigeic or endogeic earthworms since it would be possible for them to inhabit the soil depths that are expected to be found on the agricultural green roofs. Earthworms presence is expected to be deterred when an extremely acidic pH, low organic carbon content, very low or very high soil water contents or a combination of these conditions which are outside of the earthworm's range of preference are present.

3. Methods

The methods for this study are detailed below. Study site criteria, field methods, laboratory methods, statistical analysis methods, and information about the survey submitted to agricultural green roof actors (the survey that was submitted is in Appendix D) are presented. Analysis of total nitrogen, ammonium content, and nitrate content was performed by SGS Agri-Food Laboratories in Guelph, Ontario, Canada, and the names of the methods they employed are listed.

3.1. Description of Study Sites

A field study was conducted to examine earthworm populations, conditions and relationships in the setting of interest; agricultural green roofs. Each study site represents one agricultural green roof. An agricultural green roof was considered here for site selection to be a roof supporting plant growth of agricultural crops that are harvested for consumption. The structure of the growing media had to extend to a large area on the roof, beyond small pots occupying the roof top, and the growing medium had to consist of a soil mixture. The structures found were either gardens directly on the roof, or in raised containers. These characteristics were the study criteria for an agricultural green roof in this study. An internet browser search was used to make a list of potential agricultural green roofs in the greater Toronto area meeting the study criteria. A contact list was made for initial call and email communications to inquire about the agricultural green roofs and the opportunity to access them for the study. Contacts were then reached out to through phone or email. The study and agricultural green roof in question was discussed with them. If there was some one else who had the information needed, that person's contact information was received, and they were contacted to discuss the study and the agricultural green roof in question. Agricultural green roofs which met the study criteria, and where contacts could be reached and agreed to grant access to the agricultural green roof during the field work portion of the study, between September 2015 to the beginning of November 2015, were included in the study. Since earthworm activity was a focus of this study the Fall 2015 period was chosen because earthworms are active in the spring and fall, and before temperatures drop to freezing overnight. The study was limited to a one-time static measurement of the study sites to investigate the hypothesis of the study, but does not explore long-term dynamics in the agricultural green roof soils.

The study included 7 agricultural green roofs which met the study criteria. A minimum of 3 study plots were to be sampled from at each agricultural green roof. The number of study plots sampled above that was determined based on the amount of time access was available to the agricultural green roof during the site visits. Some study sites required supervision during the visit, or access was only granted between a certain period that worked with the participant's schedules. Each study plot was a 35 cm by 35 cm square plot (Hale et al., 2005). Each study plot was marked using plastic garden edging which had been cut into 35 cm pieces, and inserted into the soil to form a square plot. Overall 34 study plots were sampled from with the breakdown being 5 study plots at roof 1, 5 study plots at roof 2, 3 study plots at roof 3, 6 study plots at roof 4, 4 study plots at roof 5, 6 study plots at roof 6, and 5 study plots at roof 7. Site visits were only scheduled on days with no rain, and no large rain events within the preceding 24 hours of the site visit to avoid sampling water logged or recently drained soils which could introduce confounding variables and interfere with the ability to obtain usable results. This helped to as best as possible in an uncontrolled environment control for outside water sources, and more closely resemble baseline levels of water conditions present due to the green roof characteristics and activities occurring at that green roof.

3.2. Soil Sampling

After a study plot was set up, soil samples were taken using a soil corer. Soil cores we taken throughout the study plot randomly, and then carefully dislodged into medium sized, labeled, freezer Ziploc bags. The amount of soil cores taken per plot depended on the depth of the soil. Soil cores were taken until the desired amount of soil was obtained, about 0.35 litres to 0.5 litres. Due to concerns from agricultural green roof actors and the sensitive nature of the small sized agricultural green roof environments, this amount of soil was chosen to avoid being too invasive. The depth of each soil core was recorded, and the average was taken in order to determine the average soil depth present at the study plot at the time of sampling, as it could differ from the soil depth originally present or reported by the agricultural green roof actors. The bag was then sealed and stored on ice in a cooler. They were then transported back to the laboratory and all samples from the same site were placed in a second larger freezer bag. The samples were then stored in the freezer within 4 hours of the collection of the soil until later processing.

3.3. Earthworm Sampling

To emerge earthworms from the soils, a water and mustard powder solution was used. The chemical allyl isothiocyanate (AITC) found in the mustard seeds irritates the earthworm's skin and they emerge from the soil (Coja et al., 2008). A solution of 40 grams of hot mustard powder placed in a plastic jug and topped up to 4L with water was used (Hale et al., 2005). Before use, the solution was mixed in the jug by hand to resuspend any settled mustard powder. After soil sampling within a study plot was complete, half of the jug was poured in the study plot area, and a few minutes later the remaining mixture was poured in the study plot area. Any emerging earthworms were collected using forceps and placed in a tray which had a thin layer of water on the bottom to prevent the earthworms from drying out. If the agricultural green roof actors did not want the earthworms to be removed and brought back to the laboratory, the worms in the collection tray were photographed with a ruler for scale, and notes were made about the visual appearance. Otherwise, the earthworms were transferred from the collection trays into labelled plastic containers containing 70% isopropyl alcohol, sealed, and stored on ice in a cooler (Hale et al., 2004; Hale et al., 2005).

3.4. Earthworm Preservation

The earthworms were brought back to the lab after collection and transferred into glass containers containing 10% formalin under a fume hood to fixate the earthworms' cells for preservation (Hale et al., 2004; Hale et al., 2005). The glass containers were then sealed, and placed in the refrigerator and left for a minimum of 24 hours (Hale et al., 2004; Hale et al., 2005). After this, the earthworms were transferred under a fume hood into glass containers that contained 70% isopropyl alcohol to prevent pigment bleaching in the 10% formalin, sealed, and refrigerated until earthworm identification (Hale et al., 2004; Hale et al., 2005).

3.5. Earthworm Identification

Earthworm identification was performed using a binocular microscope set at 4 times magnification. The illuminating light at the bottom was kept off because it disguised the features of the earthworms. Instead a lamp was turned on and pointed above the specimens to be able to see the features of the earthworms. Earthworms were placed on a glass slide with some preservation liquid or water to keep the earthworm from drying out under the lamp. Earthworms were identified using the earthworm identification manual for the United States and Canada by Schwert (1990) and the earthworm identification dichotomous key for the Great Lakes region by Hale (2013). Two identification keys were used because it was not possible to clearly identify male pores on the earthworms which was a common feature mentioned in the manual by Schwert (1990), so features from both keys were used to make the identification.

3.6. Soil Total Nitrogen Content

All testing for soil total nitrogen content was performed by the SGS Agri-Food Laboratories in Guelph, Ontario, Canada, using the frozen soil samples delivered to the laboratory. The Agricultural and Food Laboratory at Guelph University had been used previously for soil testing by members of the Ryerson University Faculty, and when contacted the laboratory recommended using SGS Agri-Food Laboratories to test the green roof soils. SGS Agri-Food Laboratories was ultimately chosen because they offered methods for analysis that were able to be carried out with smaller volumes of soil. The soil volumes of green roofs are shallow and too much soil was not able to be taken due to concerns from the agricultural green roof actors involved and also not to be overly invasive to the sensitive environment. The method employed was the dumas combustion method. Results were provided to two significant digits.

3.7. Soil Ammonium Content

All testing for soil total nitrogen content was performed by the SGS Agri-Food Laboratories in Guelph, Ontario, Canada, using the frozen soil samples delivered to the laboratory. The method employed was KCl extraction. Results were provided to one significant digit.

3.8. Soil Nitrate Content

All testing for soil total nitrogen content was performed by the SGS Agri-Food Laboratories in Guelph, Ontario, Canada, using the frozen soil samples delivered to the laboratory. The method employed was KCl extraction. Results were provided to one significant digit.

3.9. Soil Water Content (Loosely Bound)

Soil moisture content considered here is for loosely bound water, which is readily available to plants (Wang et al., 2011b). For each study plot, 5 grams of soil, which had been sieved through 2mm mesh, was measured using an analytical balance into crucibles which were previously weighed and labeled (Pansu & Gautheyrou, 2006; Wang et al., 2011a). A drying oven was preheated to 105°C at which loosely bound water would begin to be removed from the soil samples (Heiri et al., 2001; Wang et al., 2011a; Wang et al., 2011b). Soil samples were dried for 24 hours in the drying oven (Heiri et al., 2001; Pansu & Gautheyrou, 2006; Wang et al., 2011b). Once dried, the samples were removed from the oven and weighed (Pansu & Gautheyrou, 2006). The percentage difference in mass between the original soil samples and the oven dried soil samples were calculated to determine the percent soil moisture content, by weight, of each study plot sample (Pansu & Gautheyrou, 2006). Three significant digits was chosen for presentation of results. For all methods which required soil samples to be dried before further processing, this was the method employed for drying the soil.

3.10. Soil Organic Carbon Content

After 5 grams of soil was oven-dried and weighed, crucibles containing the soil samples were used to calculate soil organic carbon content through loss on ignition (Heiri et al., 2001). A muffle furnace was preheated to 550°C, and once heated soil samples were burned for 4 hours. This temperature and time for burning were chosen based on the following literature presented along with the details of the method. At 550°C, most soil organic carbon would be able to be lost through combustion (Heiri et al., 2001; Hoogsteen et al., 2015). At this temperature, inorganic carbon is removed from the soil sample and removal of other materials such as mineralogical salts, and tightly bound water due to clay lattice breakdown may occur (Heiri et al., 2001). This does not proceed extensively at 550°C and if the time at ignition temperature is kept to what is needed only, while near complete combustion of organic carbon can still occur (Heiri et al., 2001). Crucibles containing the previously oven-dried soil sampled were placed in the muffle furnace using tongs. Soil samples were left in the muffle furnace at the ignition temperature for 4 hours at which point the rate of continued loss or organic carbon is minimal (Heiri et al., 2001). The muffle furnace was then turned off and samples were left to cool in the muffle furnace overnight. The furnace-burned soil samples were then weighed. The percentage difference in mass between the oven-dried soil sample and furnace-burned soil samples were calculated to determine the percent soil organic matter content, by weight, for each study plot sample, which was converted to organic carbon content using a factor of 0.58, based on the commonly applied assumption that organic matter is made up of 58% organic carbon (Lunt, 1931; Howard & Howard, 1990; Pribyl, 2010). Three significant digits was chosen for presentation of results. According to the Canadian System of Soil Classification, organic soils are soils which contain 17% or higher organic carbon content, or a 30% or higher organic matter content (Canadian Agricultural Services Coordinating Committee & Soil Classification Working Group, 1998). This classification is made use of here, however to better understand the level of organic carbon below this threshold, a comprehensive review and testing of alternative classification systems is considered (Huang et al., 2009). Mineral soils with between 15% to 30% organic matter content (and the corresponding organic carbon content value based on the 0.58 conversion factor) will be considered a mineral soil with high amounts of organic matter, and mineral soils with between 3% to 15% organic matter content (and the corresponding organic carbon content value based on the 0.58 conversion factor) will be considered a mineral soil with a low to medium amounts of organic matter (Huang et al., 2009).

3.11. Soil pH

Soil pH was measured using an Oakton 35617 series benchtop pH meter. The soil samples were treated as organic soils and so a 5 gram soil sample was used instead of a 10 gram sample to avoid inaccurate readings (Van Lierop & MacKenzie, 1977; Kalra & Maynard, 1991; Kalra, 1995; Bolan & Kandaswamy, 2005). The soils at roof 4 had lower organic carbon contents, and the pH measurement could be higher than the actual pH of the soil samples due to the 1:4 ratio applied for organic soils. A 5 gram dried soil sample from each study plot was lightly crushed and weighed into labeled 25ml test tubes (Kalra, 1995). 20mL of Millipore deionized water was added to each test tube (Kalra, 1995). Each test tube was agitated by hand to thoroughly mix the soil with the water. The test tubes were then left for a minimum of 30 minutes so the sediments could settle out of the aqueous solution and avoid obscuring the pH probe (Kalra & Maynard, 1991; Kalra, 1995). Agitation by hand was chosen over mechanical agitation because this was the chosen method in the pH method followed here. A calibrated pH probe was then inserted into the test tube above the settled sediments and pH measurement was taken. After each measurement, the pH probe was submerged in a beaker of Millipore deionized water, and then separately rinsed with Millipore deionized water before being inserted into the next sample. The pH metre produced results to 2 significant digits.

3.12. Soil Clay Content

Laser diffractometry was used to perform particle size analysis of the soil samples and determine the clay content. The method from Miller and Schaetzl (2012) was followed. The materials, amounts of each material, and deviations from the method presented by Miller and Schaetzl (2012) are as follows. Air dried soil was lightly crushed, sifted through 2mm mesh, and 0.3 grams from each study plot was weighed and added to a labeled 25mL plastic test tube. A 5% sodium hexametaposphate solution was created by combining 50 grams of sodium hexametaphosphate to 1L of Millipore deionized water (Eshel et al., 2004; Zobeck, 2004; Arriaga et al., 2006; Keller & Gee, 2006; Di Stefano et al., 2010). To the test tube 5 mL of the 5% sodium hexametaphosphate dispersing solution, and 15 mL of Millipore deionized water was added and shaken by hand. The laser used was the Malvern Mastersizer 2000, and the sample dispersion unit used was the Hydro 2000S. In Miller and Schaetzl (2012), the dispersion unit used is the Hydro 2000MU, but the loading unit available for the study was the Hydro 2000S. The Hydro 2000S holds less liquid than the Hydro 2000MU, and can only hold up to 150mL. The complete soil sample solution prepared could not be added or else the laser obscuration would be too high. Instead, the samples were shaken by hand to create a homogenous mixture, and added to the tank which was filled with distilled water until the laser obscuration was in the range of 5% to 15%. Distilled water was used for this analysis because it was recommended by the laboratory members who use the Malvern Mastersizer 2000 for particle size analysis. Ion effects would not interfere with the nature of this analysis since the measurement was of physical size and not chemical, or biological in nature. From there measurement continued as with Miller and Schaetzl (2012). The machine was thoroughly flushed to clean it between each sample loading and measurement. The Canadian System of Soil Classification was used to analyze results and the level of clay in the soil (Canadian Agricultural Services Coordinating Committee

& Soil Classification Working Group, 1998). The clay content of soil was presented as the average measurement over 5 runs through the Malvern Mastersizer 2000, and three significant digits was chosen for presentation of results.

3.13. Statistical Analysis

Descriptive statistics were compiled in Excel for measured pH, soil water content, soil organic carbon content, soil average clay content, soil total nitrogen content, soil ammonium content, soil nitrate content, and soil earthworm count. This was done at a study site level, where the parameter values for all study plots on one roof were used to determine the descriptive statistics for that study site.

Multiple regression was performed in SAS statistical analysis software to determine if there was a relationship between three variables: earthworm abundance; ammonium content; and nitrate content, and possible explanatory variables. The relationship between earthworm abundance and the soil parameters soil water content, soil organic carbon content, soil depth, and soil total nitrogen content was analyzed to determine if any of these variables could predict earthworm abundance. The model was run iteratively, through backward stepwise elimination beginning with all explanatory variables included, removing non-significant factors, and re-running the model. Multiple regression was then used to test the hypothesis that earthworms could influence the soil bioavailable nitrogen content (ammonium and nitrate). Multiple regression was performed to control for potentially correlated explanatory variables. For ammonium, potentially correlated explanatory variables included soil water content, soil organic carbon content, soil total nitrogen content, and soil depth. For nitrate, potentially correlated explanatory variables included soil water content, soils organic carbon content, soil total nitrogen content, soil ammonium content, and soil depth. Soil pH was not included as an explanatory variable because they were all within the same characteristic pH range: between neutral and approaching slightly acidic. Soil clay content was not included as an explanatory variable because all measures had the same characteristic of a low clay content. For the multiple regression analysis of earthworm abundance, a transformation was determined in the SAS program and applied to soil water content in order to fit a linear relationship between soil water content and earthworm count. In the form of $Y = aX^b$, a was determined to be 0.000153 and b was determined to be 2.6458.

Regression statistics were performed in excel for the association between soil clay content and soil ammonium content, and soil clay content and soil nitrate content. A significance level of 0.05 was used to classify p values as being statistically significant if they were equal to or less than 0.05.

3.14. Agricultural Green Roof Actors Survey

A proposal was submitted and approved by the Ryerson University research ethics board, along with a consent form and the set of questions that were to be answered by the participants. Participants were the individuals involved with the agricultural green roof who had the information necessary to answer the questions, and they were referred to as the agricultural green roof actors since they are actors in the application being investigated. Participants were either called, left a phone message, or emailed asking to answer questions about the agricultural green roof they were involved with, and sign and return a consent form. Questions were related to the characteristics of the green roof, and activities taking place on the green roof. For participants who responded, the answers were used in analysis when the information could aid the discussion. The amount and detail of information the agricultural green roof actors were able to provide varied depending on the study site. Detailed information about exact amounts of parameters in soil additions and amendments to soils, including organic carbon, ammonium, and nitrate were not collected or not available. The survey was meant to supplement and strengthen the analysis of measured results with additional insight from knowledge base of each roof. In order to determine the exact amount of these parameters present in inputs, a more controlled study would need to take place that directly measures the amounts of different components in these inputs. The survey submitted to the agricultural green roof actors can be viewed in Appendix D. In regard to potential earthworm introduction, this could occur through their eggs or hatched earthworms present in soils mixtures, earthworm casting mixtures, or vermicompost mixtures produced by earthworms. Earthworms or their eggs could also intentionally be introduced into the agricultural green roof soils. These possible routes of introduction of earthworms could lead to earthworm populations in the soils, or they could not result in populations of earthworms present in the soil. Surveys included questions about the use or occurrences of these activities.

4. Results

4.1. Plot Summary

Tables 1 to Table 14 summarize the data collected for each study plot. Data in the tables was collected from field observations, laboratory analysis, and the surveys submitted to the agricultural green roof actors.

Table 1 summarizes the measured conditions for plots 1A to 1E on Roof 1. All plots on roof 1 have organic soils, pH values in the neutral range with the lowest approaching slightly acidic, and a low clay content. All plots have a high soil water content, except for plot 1E which has a low soil water content. There were no earthworms found at plots 1A, 1B, and 1E. A low number of earthworms were found at plots 1C, and 1D, and the lowest possible taxonomic identification identifies these earthworms as either *Eisenia eiseni* or *Eisenia fetida*, which are both epigeic earthworms. Soil ammonium levels at all plots on roof 1 are high. There is a moderate amount of nitrate at plots 1B and 1C, low levels at plot 1A, and very low levels at plots 1D and 1E.

Table 2 summarizes the most relevant information about the characteristics and conditions present at plots 1A to 1E on Roof 1 gathered from field observations and from the information provided by the agricultural green roofs actors. Additional information not in the table is that the garden soils at roof 1 are tested regularly during the growing season. These examinations include recommendations on maintenance requirements going forward based on the test results.

Table 3 summarizes the measured conditions for plots 2A to 2E on Roof 2. Plot 2A has inorganic soil with a high amount of organic components, while plots 2B, 2C, 2D, and 2E have organic soils. All plots on roof 2 have neutral pH values, low clay content, and a high water content. Many earthworms were found at all plots on roof 2, with a very high number at plot 2A, and 2B. The lowest possible taxonomic identification identifies these earthworms as either *Eisenia eiseni* or *Eisenia fetida*, which are both epigeic earthworms. Soil ammonium levels at all plots on roof 2 are high, especially at plots 2A, 2B, 2C, and 2E. Soil nitrate levels at plots 2A and 2B are moderate, while there are very high levels at plots 2C, 2D, and 2E.

Table 1. Summary of measured conditions for plots 1A, 1B, 1C, 1D, and 1E on Roof 1.

	1A	1B	1C	1D	1E
Soil pH	6.6	6.62	6.86	6.8	6.68
Soil Water Content (Loosely Bound) (%)	52.756	58.595	59.979	60.672	39.285
Soil Organic Carbon Content (%)	13.634	12.281	11.524	11.745	18.944
Soil Clay Content (%)	1.678	2.076	2.218	1.860	1.594
Soil Total Nitrogen (%)	1.16	0.97	1.10	0.75	0.96
Soil Ammonium (ppm)	48.4	48.3	48.9	45.1	44.9
Soil Nitrate (ppm)	9.8	29.2	19.3	3.4	1.8
Soil Earthworm Count	0	0	2	1	0
Earthworm Identification	n/a	n/a	*Eisenia eiseni* or *Eisenia fetida*	*Eisenia eiseni* or *Eisenia fetida*	n/a
Earthworm Ecological Group	n/a	n/a	Epigeic	Epigeic	n/a

Table 2. Summary of characteristics and conditions for plots 1A, 1B, 1C, 1D, and 1E on Roof 1

	Plot 1A	Plot 1B	Plot 1C	Plot 1D	Plot 1E
Vegetation	Corn	Green Beans	Squash	Sage	Sweet Grass, Grasses, nearby Service Berries, and Wild Flowers
Type of Garden	Grown directly on roof	Grown directly on roof	Grown directly on roof	Grown Directly on roof	Grown directly on roof
Soil Depth	8 inches	6 inches	8 inches	6 inches	16 to 24 inches
Irrigation	Hand watered or irrigation system. Irrigation type and amount based on water needs of plants based on monthly site assessments.				
Observed Soil Moisture	Moist	Moist	Moist	Very Moist	Slightly Dry
Shade	Not shaded	Slight shade by trees, plant provides ground cover shade	Slightly shaded by trees	Not shaded	Partially shaded by wall and buildings
Known earthworm casting additions	Not added	Not added	Not added	Not added	Not added
Known introduction of earthworms	None known	None known	None known	None known	None known
Known use of vermicompost	None known	None known	None known	None known	None known

Table 3. Summary of measured conditions for plots 2A, 2B, 2C, 2D, and 2E on Roof 2.

	2A	2B	2C	2D	2E
Soil pH	6.79	7.13	7.02	6.92	7.03
Soil Water Content (Loosely Bound) (%)	52.846	63.260	64.051	64.097	65.681
Soil Organic Carbon Content (%)	7.127	9.462	9.001	10.454	10.095
Soil Clay Content (%)	6.141	1.831	1.618	1.311	1.517
Soil Total Nitrogen (%)	0.82	1.39	1.59	1.60	1.42
Soil Ammonium (ppm)	54.6	59.6	54.9	35.5	60.2
Soil Nitrate (ppm)	22.3	23	85.8	137.7	48.8
Soil Earthworm Count	33	34	15	9	10
Earthworm Identification	*Eisenia eiseni* or *Eisenia fetida*	*Eisenia eiseni* or *Eisenia fetida*	*Eisenia eiseni* or *Eisenia fetida*	*Eisenia eiseni* or *Eisenia fetida*	*Eisenia eiseni* or *Eisenia fetida*
Earthworm Ecological Group	Epigeic	Epigeic	Epigeic	Epigeic	Epigeic

Table 4 summarizes the most relevant information about the characteristics and conditions present at plots 2A to 2E on Roof 2 gathered from field observations and from the information provided by the agricultural green roofs actors. Additional information not in the table is that Plots 2B, 2C, 2D, and 2E all had received a large application of compost which contained earthworm castings, eggs, and earthworms. The compost was raked in over time toward one location which included the location of plot 2D. This plot received inputs from this compost mixture for the longest period of time. The same compost mixture as mentioned above was not applied to Plot 2A because the garden in this area includes a rotation of legumes which fix nitrogen and provide a source of nitrogen to the pool in the soil.

Table 5 summarizes the measured conditions for plots 3A to 3C on Roof 3. All plots on roof 3 have organic soils, neutral pH values, and a low clay content. Plots 3A, and 3B have a low soil water content, and plot 3C has a high soil water content. There were no earthworms found at plots 3A, and 3B. A few earthworms were found at plot 3C, and the lowest possible taxonomic identification identifies these earthworms as either *Eisenia eiseni* or *Eisenia fetida*, which are both epigeic earthworms. Soil ammonium levels at plots 3B and 3C are high. Soil nitrate levels at all plots on roof 3 are low.

Table 6 summarizes the most relevant information about the characteristics and conditions present at plots 3A to 3C on Roof 3 gathered from field observations and from the information provided by the agricultural green roofs actors. Additional observations not in the table or worth highlighting are that the soil at plot 3C was compact and wet, with a shallower soil depth than originally present. In contrast, the soils at plot 3A and 3B were on the dry side.

Table 7 summarizes the measured conditions for plots 4A to 4F on Roof 4. All plots on roof 4 have mineral soils with a low organic carbon content at plots 4C, 4D, and 4E and a moderate organic carbon content at plots 4A, and 4B. All plots have neutral pH values, a low clay content, and a very low soil water content. This was the only roof where a low total nitrogen content was measured. There was a moderate ammonium content at all plots, a moderate nitrate content at plots 4A and 4B, and a low nitrate content at plots 4C, 4D, 4E, and 4F. There were no earthworms found at plots 4A, 4B, and 4D. A low amount of earthworms were found at plots 4C, 4E, and 4F. The lowest possible taxonomic identification identifies these earthworms as either *Eisenia eiseni* or *Eisenia fetida*, which are both epigeic earthworms.

Table 4. Summary of characteristics and conditions for plots 2A, 2B, 2C, 2D, and 2E on Roof 2.

	Plot 2A	Plot 2B	Plot 2C	Plot 2D	Plot 2E
Vegetation	Beans, Peas, Rye (just planted), Basil, Cilantro, Borage, Nasturtium, Calendula	Cucumber, Squash, Melon, Zucchinis, Clover cover crop (just planted)	Potatoes, nearby Tomatoes	Potatoes, nearby Tomatoes	Green Peppers, Red Chili Peppers
Type of Garden	Grown directly on roof	Grown directly on roof	Grown directly on roof	Grown directly on roof	Grown directly on roof
Soil Depth	12 inches	12 inches	12 inches	12 inches	12 inches
Irrigation	Drip tape by Dubois Agrinovation. 24 to 48 hours of irrigation system usage during weeks where no rain was forecast. No usage during weeks where rain is forecast.				
Observed Soil Moisture	Moist	Moist	Moist	Moist	Moist
Shade	Partially shaded by building	Partially shaded by building	Partially by other tomato plants	Partially by other tomato plants	Not shaded
Known earthworm casting additions	Yes, and eggs mixed with castings	Yes, and eggs mixed with castings	Yes, and eggs mixed with castings	Yes, and eggs mixed with castings	Yes, and eggs mixed with castings
Known introduction of earthworms	None known	Yes	Yes	Yes	Yes
Known use of vermicompost	Yes	Yes	Yes	Yes	Yes

Table 5. Summary of measured conditions for plots 3A, 3B, and 3C on Roof 3.

	Plot 3A	Plot 3B	Plot 3C
Soil pH	7.01	6.88	6.73
Soil Water Content (Loosely Bound) (%)	37.187	49.758	67.940
Soil Organic Carbon Content (%)	19.348	15.503	10.897
Soil Clay Content (%)	0.905	1.133	2.408
Soil Total Nitrogen (%)	0.94	0.97	0.95
Soil Ammonium (ppm)	26	34.5	39.2
Soil Nitrate (ppm)	3.4	3.6	2.5
Soil Earthworm Count	0	0	3
Earthworm Identification	n/a	n/a	*Eisenia eiseni* or *Eisenia fetida*
Earthworm Ecological Group	n/a	n/a	Epigeic

Table 8 summarizes the characteristics and conditions present at plots 4A to 4F on roof 4 gathered from field observations and from the information provided by the agricultural green roofs actors. Additional information not included in the table or worth highlighting is that most areas of the soils on roof 4 were a couple to a few inches shallower than originally present. The soils on roof 4 were also noticeably compact, with soils at plot 4D being the most compact. To avoid disturbing the gardens, additions of soil to maintain the depth are minimal. The areas with the deepest soil depths, including plots 4C, 4E, and 4F, are the gardens that were planted more recently than the gardens with the shallower soils, and included plots 4A, 4B, and 4D.

Table 6. Summary of characteristics and conditions for plots 3A, 3B, and 3C on Roof 3.

	Plot 3A	Plot 3B	Plot 3C
Vegetation	Tomatoes	Chili Peppers	Basil, and other Herbs, Clover, Mosses
Type of Garden	Raised Container	Raised Container	Grown directly on roof
Soil Depth	6 inches	6 inches	6 inches, deepest soil core possible was 4 inches, indicates shallower soil depth then originally present
Irrigation	Drip irrigation, used twice a week		
Observed Soil Moisture	Dry	Slightly Dry	Very Moist
Shade	Partially shaded by other tomato plants	Partially shaded by buildings	Fully shaded by buildings
Known earthworm casting additions	None known	None known	None known
Known introduction of earthworms	None known	None known	None known
Known use of vermicompost	None known	None known	None known

Table 9 summarizes the measured conditions for plots 5A to 5D on Roof 5. All plots on roof 5 have organic soils, neutral pH values, a low clay content, and a low water content. There were no earthworms found at any plots on roof 5. Soil ammonium levels at all plots on roof 5 are high. Soil nitrate levels at plot 5A are also high, with a moderate nitrate level at plots 5B, 5C, and 5D.

Table 7. Summary of measured conditions for Plot 4A, 4B, 4C, 4D, 4E, and 4F on Roof 4.

	Plot 4A	Plot 4B	Plot 4C	Plot 4D	Plot 4E	Plot 4F
Soil pH	7	6.8	6.85	6.79	6.83	6.73
Soil Water Content (Loosely Bound) (%)	22.729	24.198	28.129	19.884	28.551	26.003
Soil Organic Carbon Content (%)	4.928	4.688	3.834	2.698	4.366	4.401
Soil Clay Content (%)	8.006	11.319	10.084	14.282	6.360	8.627
Soil Total Nitrogen (%)	0.58	0.47	0.38	0.29	0.53	0.41
Soil Ammonium (ppm)	13.8	19.2	17.8	8.6	22	22.1
Soil Nitrate (ppm)	12.4	6.8	4.6	2.9	4.4	3.5
Soil Earthworm Count	0	0	1	0	3	2
Earthworm Identification	n/a	n/a	*Eisenia eiseni* or *Eisenia fetida*	n/a	*Eisenia eiseni* or *Eisenia fetida*	*Eisenia eiseni* or *Eisenia fetida*
Earthworm Ecological Group	n/a	n/a	Epigeic	n/a	Epigeic	Epigeic

Table 8. Summary of characteristics and conditions for Plot 4A, 4B, 4C, 4D, 4E, and 4F on Roof 4.

	Plot 4A	Plot 4B	Plot 4C	Plot 4D	Plot 4E	Plot 4F
Vegetation	Eggplant	Legumes, Beans. Rotate with Greens Roots, Peas	Radishes	Tea Garden, Perennials, Herbs, Thyme	Tomato and Chilis	Cabbage, Kale, Brussel Sprouts, Perennials
Type of Garden	Grown directly on roof	Grown directly on roof	Grown directly on roof	Grown directly on roof	Grown directly on roof	Grown directly on roof
Soil Depth	7 to 8 inches, deepest soil core possible was 6 inches, indicates shallower soil depth then originally present	7 to 8 inches, deepest soil core possible was 4 inches, indicates shallower soil depth then originally present	7 to 8 inches	7 to 8 inches, deepest soil core possible was 4 inches, indicates shallower soil depth then originally present	7 to 8 inches	7 to 8 inches
Irrigation	Drip Irrigation System					
Observed Soil Moisture	Dry	Slightly Dry	Slightly Dry	Moist	Moist	Moist
Shade	Not shaded	Partially shaded by buildings, trees, and other bean plants	Partially shaded by buildings	Partially shaded by buildings	Partially shaded by buildings and other tomato plants	Partially shaded by buildings
Known earthworm casting additions	Yes	Yes	Yes	Yes	Yes	Yes
Known introduction of earthworms	None known	None known	None known	None known	None known	None known
Known use of vermicompost	Yes	Yes	Yes	Yes	Yes	Yes

Table 9. Summary of measured conditions for Plot 5A, 5B, 5C, and 5D on Roof 5.

	Plot 5A	Plot 5B	Plot 5C	Plot 5D
Soil pH	6.94	6.84	6.98	6.88
Soil Water Content (Loosely Bound) (%)	44.328	37.451	37.883	46.606
Soil Organic Carbon Content (%)	12.597	14.084	14.768	11.677
Soil Clay Content (%)	3.746	3.658	3.627	4.915
Soil Total Nitrogen (%)	1.04	0.94	1.03	1.10
Soil Ammonium (ppm)	46	39.6	35.9	56.2
Soil Nitrate (ppm)	31.3	13	10.7	26.9
Soil Earthworm Count	0	0	0	0
Earthworm Identification	n/a	n/a	n/a	n/a
Earthworm Ecological Group	n/a	n/a	n/a	n/a

Table 10 summarizes the most relevant information about the characteristics and conditions present at plots 5A to 5D on Roof 5 gathered from field observations and from the information provided by the agricultural green roofs actors. Additional information not included in the table is that the container beds were raised off the roof and there was a space that could be seen between the bottom of the container bed and the roof. It was observed that water poured on the soil drained easily and quickly through the soil and out from the bottom of the container bed. Information was also provided noting the quick drainage of water from the soil and that the soil dries out quickly.

Table 10. Summary of characteristics and conditions for Plot 5A, 5B, 5C, and 5D on Roof 5.

	Plot 5A	Plot 5B	Plot 5C	Plot 5D
Vegetation	Tomatoes	Beets	Kale	Basil, Tomatoes, Eggplant, and Peppers
Type of Garden	Raised Container	Raised Container	Raised Container	Raised Container
Soil Depth	18 inches	18 inches	18 inches	18 inches
Irrigation	Overhead sprinklers and watering with watering cans were used at the start of the season. Drip Irrigating System was installed and used thereafter. Irrigation occurs every week day, otherwise the soil is seen to get dry.			
Observed Soil Moisture	Moist	Moist	Slightly Dry	Moist
Shade	Partially shaded by buildings	Partially shaded by buildings	Partially Shaded by buildings, and other plants	Partially shaded by buildings
Known earthworm casting additions	Yes	Yes	Yes	Yes
Known introduction of earthworms	None known	None known	None known	None known
Known use of vermicompost	Yes	Yes	Yes	Yes

Table 11 summarizes the measured conditions for plots 6A to 6F on Roof 6. All plots on roof 6 have organic soils, neutral pH values, and a low clay content. There is a high water content at plots 6A, 6C, 6D, 6E, and 6F, and a low water content at plot 6B. There were no earthworms found at plots 6B, and 6E. A few earthworms were found at plot 6C, and many earthworms were found at plots 6A, 6D and 6F, with a very high number found at plot 6A. The lowest possible taxonomic identification identifies these earthworms as either *Eisenia eiseni* or *Eisenia fetida*, which are both epigeic earthworms. Soil ammonium levels at plots 6A, 6C, 6D, 6E, and 6F are high with a moderate level at plot 6B. Soil nitrate levels at plot 6A, and 6C are high, with a moderate level at plots 6B, 6D, and 6E, and a low level at plot 6F.

Table 12 summarizes the most relevant information about the characteristics and conditions present at plots 6A to 6F on Roof 6 gathered from field observations and from the information provided by the agricultural green roofs actors. Additional information not included in the table or worth highlighting is that all crops are rotated on roof 6, including the crops at the study plots, with multiple crops being grown throughout a single growing season. Earthworms have been seen in the soils on roof 6 by individuals involved with the green roof. All study plots on roof 6 had soils which were a couple to a few inches shallower than the 12 inches of soil originally present. Plot 6D was indicated to become flooded with water often due a possible break in the barrier allowing water from the raised contained next to it to drain into this garden.

Table 13 summarizes the measured conditions for plots 7A to 7E on Roof 7. All plots on roof 7 have organic soils, neutral pH values, a low clay content, and a high water content. There were no earthworms found at plots 7C, and 7D, a low amount found at plot 7B, and many found at plots 7A, and 7E. The lowest possible taxonomic identification identifies these earthworms as either *Eisenia eiseni* or *Eisenia fetida*, which are both epigeic earthworms. Soil ammonium levels at plots 7D, and 7E are high with moderate levels at plots 7A, 7B, and 7C. Soil nitrate levels at plots 7A, 7B, 7C, and 7E are moderate with a low level at plot 7D.

Table 14 summarizes the most relevant information about the characteristics and conditions present at plots 7A to 7E on Roof 7 gathered from field observations and from the information provided by the agricultural green roofs actors. Additional information not included in the table is that the garden's structure was consistent with soil mounds where plants were grown. The mounded soil was twice as deep as the soil at the bottom of the mounds.

Table 11. Summary of measured conditions for Plot 6A, 6B, 6C, 6D, 6E, and 6F on Roof 6.

	Plot 6A	Plot 6B	Plot 6C	Plot 6D	Plot 6E	Plot 6F
Soil pH	6.89	6.9	6.71	6.93	6.85	6.84
Soil Water Content (Loosely Bound) (%)	62.876	46.463	60.750	61.387	54.227	62.803
Soil Organic Carbon Content (%)	10.219	10.573	12.761	10.115	11.928	10.923
Soil Clay Content (%)	3.169	2.162	2.252	3.657	2.197	2.139
Soil Total Nitrogen (%)	1.13	0.85	1.02	0.98	1.03	1.11
Soil Ammonium (ppm)	52.9	25.9	52.7	47.6	44.3	48.3
Soil Nitrate (ppm)	39.5	21.3	31.3	7.6	9.5	5.7
Soil Earthworm Count	37	0	5	9	0	14
Earthworm Identification	*Eisenia eiseni* or *Eisenia fetida*	n/a	*Eisenia eiseni* or *Eisenia fetida*	*Eisenia eiseni* or *Eisenia fetida*	n/a	*Eisenia eiseni* or *Eisenia fetida*
Earthworm Ecological Group	Epigeic	n/a	Epigeic	Epigeic	n/a	Epigeic

Table 12. Summary of characteristics and conditions for Plot 6A, 6B, 6C, 6D, 6E, and 6F on Roof 6.

	Plot 6A	Plot 6B	Plot 6C	Plot 6D	Plot 6E	Plot 6F
Vegetation	Marigolds, Onions, Garlic, Cornflower, and Mullein have been rotated	Peas, Beans, Tomatoes, Clover, and Carrots have been rotated	Onions, Beets, Swiss Chard, Kale, Carrots, Peas, Calendula, Okra, Nettle, and Parsley have been rotated	Bee Balm, Purple Cornflower, Motherwort, Catnip, Wood Betony, Burgamot, Lobilia, and Onions have been rotated	Tomatoes, Eggplant, and Carrots have been rotated	Lettuces, Beans, Onions, Swiss Chard, and Radishes have been rotated
Type of Garden	Grown directly on roof	Raised Container	Raised Container	Grown directly on roof	Raised Container	Grown directly on roof
Soil Depth	12 inches, deepest soil core possible was 9.5 inches, indicates shallower soil depth then originally present	12 inches, deepest soil core possible was 7 inches, indicates shallower soil depth then originally present	12 inches, deepest soil core possible was 8.5 inches, indicates shallower soil depth then originally present	12 inches, deepest soil core possible was 6.5 inches, indicates shallower soil depth then originally present	12 inches, deepest soil core possible was 7 inches, indicates shallower soil depth then originally present	12 inches, deepest soil core possible was 7 inches, indicates shallower soil depth then originally present
Irrigation	Drip Irrigation System					
Observed Soil Moisture	Very Moist	Moist	Moist	Very Moist	Very Moist	Very Moist
Shade	Partially shaded by buildings	Not shaded	Partially shaded by buildings and trees	Partially shaded by buildings	Partially shaded by buildings & plants	Partially shaded by buildings
Known earthworm casting additions	Yes	Yes	Yes	Yes	Yes	Yes
Known introduction of earthworms	None known	None known	None known	None known	None known	None known
Known use of vermicompost	Yes	Yes	Yes	Yes	Yes	Yes

Table 13. Summary of measured conditions for Plot 7A, 7B, 7C, 7D, and 7E on Roof 7.

	Plot 7A	Plot 7B	Plot 7C	Plot 7D	Plot 7E
Soil pH	6.81	6.68	6.97	6.82	6.8
Soil Water Content (Loosely Bound) (%)	70.792	67.345	64.369	65.273	69.888
Soil Organic Carbon Content (%)	9.162	9.755	11.472	11.475	9.947
Soil Clay Content (%)	1.221	1.353	1.276	1.193	1.175
Soil Total Nitrogen (%)	1.06	1.12	0.90	1.16	1.24
Soil Ammonium (ppm)	30.6	30.6	23.9	45.3	35.1
Soil Nitrate (ppm)	8.9	10.2	6.1	5.4	9.8
Soil Earthworm Count	12	3	0	0	7
Earthworm Identification	*Eisenia eiseni* or *Eisenia fetida*	*Eisenia eiseni* or *Eisenia fetida*	n/a	n/a	*Eisenia eiseni* or *Eisenia fetida*
Earthworm Ecological Group	Epigeic	Epigeic	n/a	n/a	Epigeic

Table 14. Summary of characteristics and conditions for Plot 7A, 7B, 7C, 7D, and 7E on Roof 7.

	Plot 7A	Plot 7B	Plot 7C	Plot 7D	Plot 7E
Vegetation	Radish	Swiss Chard	Basil, Parsley, and other herbs	Green Peppers	Catnip, and Raspberries
Type of Garden	Grown directly on roof	Grown directly on roof	Grown directly on roof	Grown directly on roof	Grown directly on roof
Soil Depth	4 to 8 inches, mounded rows create high and low areas	4 to 8 inches, mounded rows create high and low areas	4 to 8 inches, mounded rows create high and low areas	4 to 10 inches, mounded rows create high and low areas	4 to 10 inches, mounded rows create high and low areas
Irrigation	Oscillating Sprinkler, some Drip Irrigation	Oscillating Sprinkler, some Drip Irrigation	Oscillating Sprinkler	Oscillating Sprinkler	Oscillating Sprinkler, Some Drip Irrigation
Observed Soil Moisture	Very Moist	Moist	Moist	Moist	Moist
Shade	Not shaded	Not shaded	Partially shaded by buildings	Partially shaded by buildings	Not shaded
Known earthworm casting additions	-	-	-	-	-
Known introduction of earthworms	-	-	-	-	-
Known use of vermicompost	-	-	-	-	-

4.2. Roof Variability, Within and Between

The sections below will compare results for each parameter using descriptive statistics and graphical illustration of the value range for each roof. Within and between roof comparison will highlight the extent that results are associated with factors involving the activities and characteristics of the individual roof, or other factors.

4.2.1. pH

Mean pH values for each roof were approximately neutral: 6.71 for roof 1; 6.98 for roof 2; 6.87 for roof 3; 6.83 for roof 4; 6.91 for roof 5; 6.85 for roof 6; 6.82 for roof 7 (Table A1). There is little variation for what is seen within each individual roof since all pH values are neutral with the lowest ones approaching slightly acidic with the following coefficients of variation: 0.017 for roof 1; 0.018 for roof 2; 0.020 for roof 3; 0.013 for roof 4; 0.009 for roof 5; 0.011 for roof 6; 0.015 for roof 7 (Table A1). Fig. 1 shows the soil pH value distribution for each roof. Roofs 2 to 7 all have closely overlapping value ranges, with all values representing a pH from approaching slightly acidic to a neutral pH. Roof 1 has a value range which slightly overlaps the pH ranges for roofs 2 to 7. Roof 1 has a slightly more acidic range of pH values; however, all values are still neutral to approaching slightly acidic so the between roof variability is minimal.

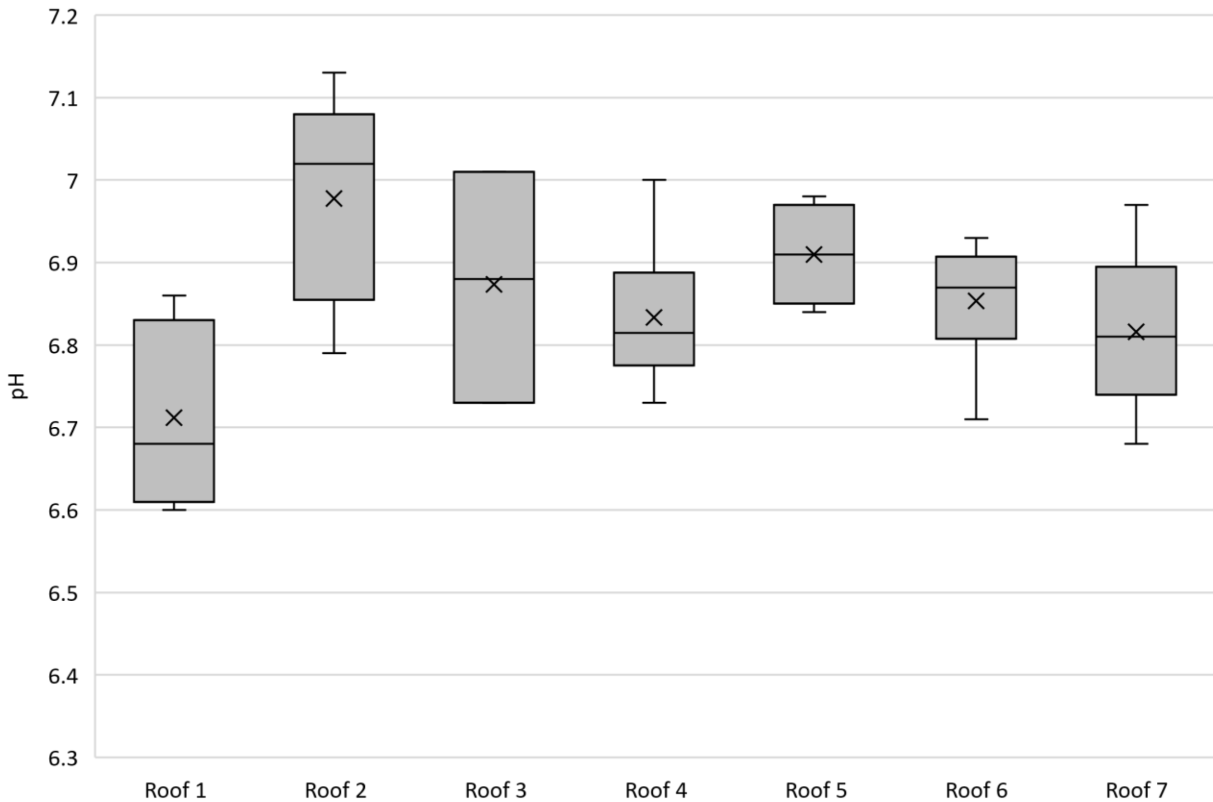

Fig. 1. pH content distribution of study plots for each study site.

4.2.2. Soil Water Content

Most mean soil water content percentage values show a high percentage, with a low percentage for roof 5 and roof 4: 54.257% for roof 1; 61.987% for roof 2; 51.628% for roof 3; 24.916% for roof 4; 41.567% for roof 5; 58.085% for roof 6; 67.533% for roof 7 (Table A2). There is little variation for what is seen within individual roofs, except for roof 1 and roof 3 which have a higher within roof variation, with the following coefficients of variation: 0.165 for roof 1; 0.084 for roof 2; 0.299 for roof 3; 0.134 for roof 4; 0.111 for roof 5; 0.112 for roof 6; 0.041 for roof 7 (Table A2). Fig. 2 shows the soil water content value distribution for each roof. Roofs 2, and 4 to 7 have small within roof variability. Roof 1 has a larger within roof variability. Roof 3 has a very large within roof variability. This matches what is seen with the descriptive statistics (Table A2). There is a large between roof variability seen with the value ranges for the roofs covering different areas, and a large section of the soil water content value spectrum from around 20% to 70% soil water content (Fig. 2). Soil water content results show a strong relationship to individual roofs, indicating effects specific to the roof, such as the green roof characteristics or activities occurring on the roof, have a strong influence on the results.

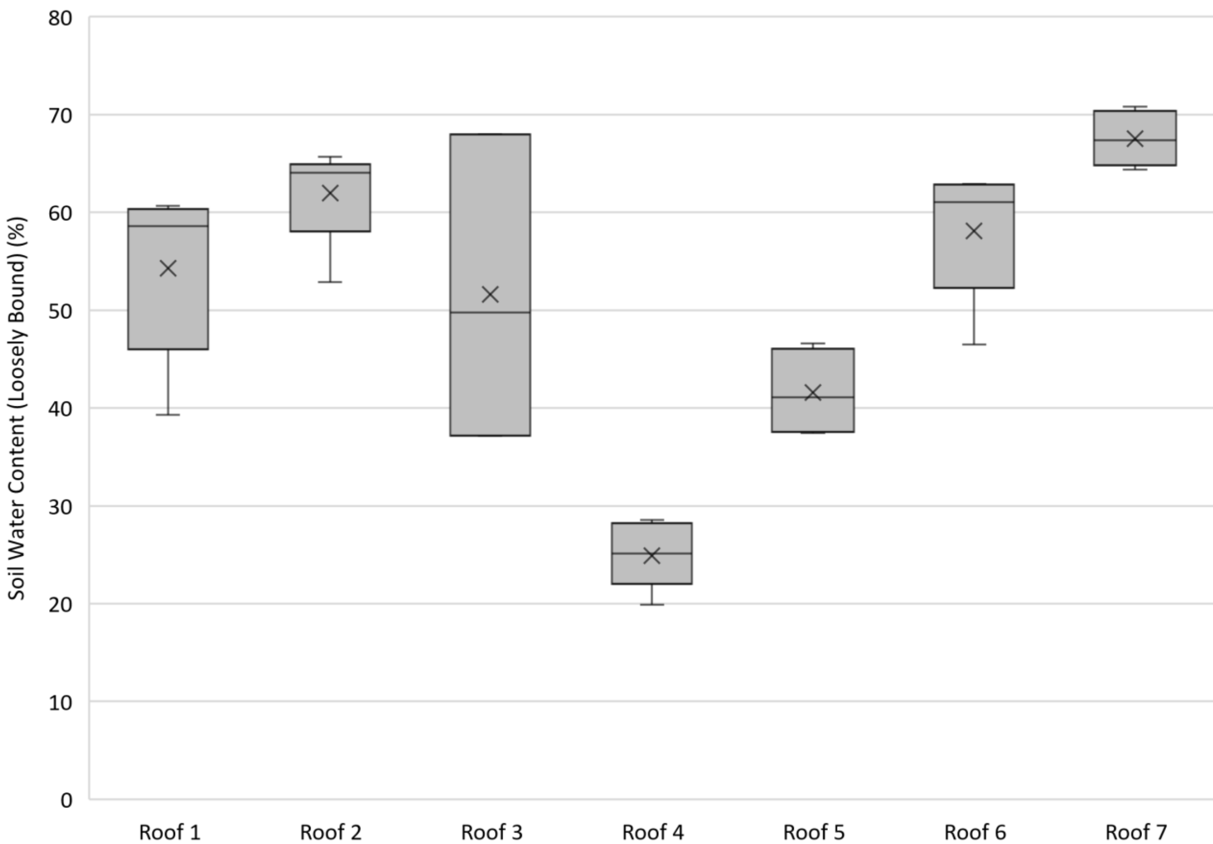

Fig. 2. Water content (loosely bound) distribution of study plots for each study site.

4.2.3. Soil Organic Carbon Content

Most mean soil organic carbon percentage values show a high percentage of organic carbon content, except for roof 4 which shows a low percentage of organic carbon content: 13.626% for roof 1; 9.227% for roof 2; 15.249% for roof 3; 4.152% for roof 4; 13.281% for roof 5; 11.087% for roof 6; 10.362% for roof 7 (Table A3). There is little variation for what is seen within individual roofs, except for roof 1 and roof 3 which have higher within roof variation, with the following coefficients of variation: 0.226 for roof 1; 0.141 for roof 2; 0.277 for roof 3; 0.193 for roof 4; 0.106 for roof 5; 0.095 for roof 6; 0.102 for roof 7 (Table A3). Fig. 3 shows the soil organic carbon content value distribution for each roof. Roofs 2, and 4 to 7 have small within roof variability. Roof 1 also has a small within roof variability but it is larger than the within roof variability of roofs 2, and 4 to 7. Roof 3 has a large within roof variability. Roofs 1 to 3, and 5 to 7 all have high soil organic carbon content value ranges. Roof 4 has a low range of soil organic carbon content values. Soil organic carbon content results show a strong relationship to individual roofs based on the within roof variabilities seen, excluding roof 3, indicating effects specific to the roof, such as the green roof characteristics or activities occurring on the roof have a strong influence on the results.

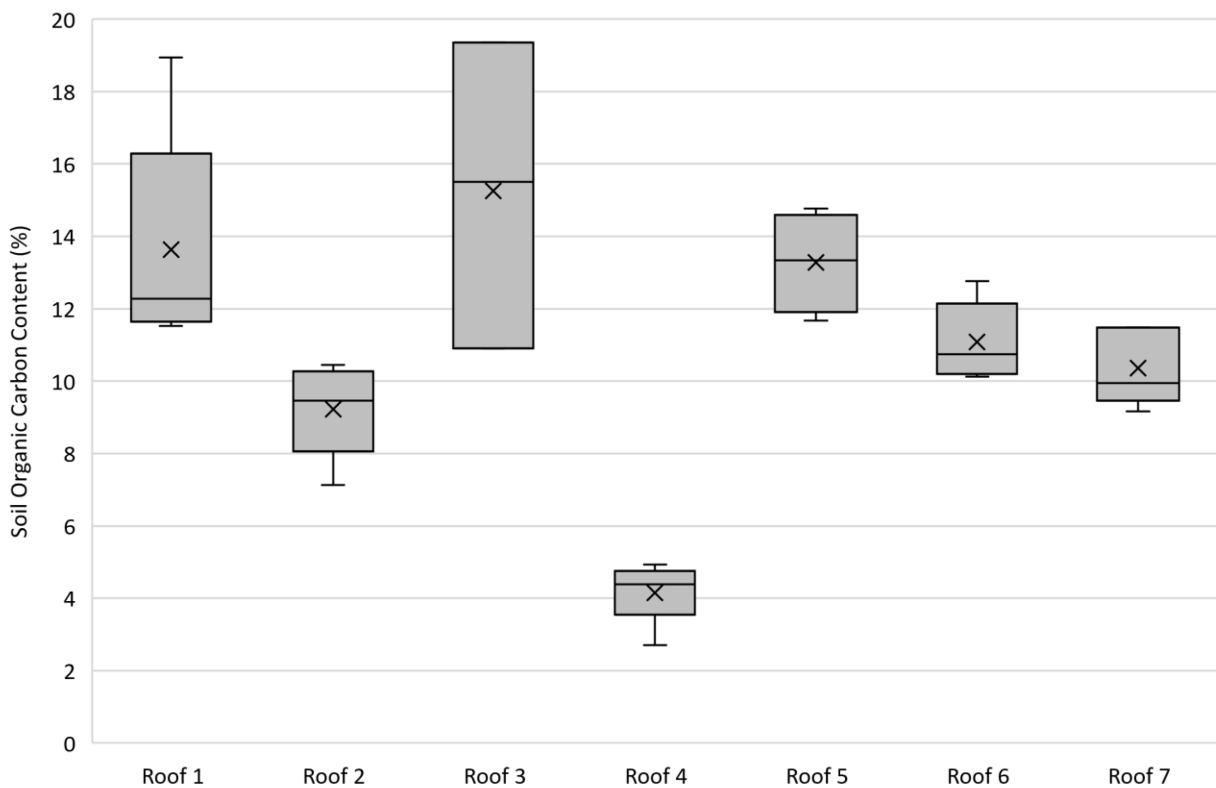

Fig. 3. Organic carbon content distribution of study plots for each study site.

4.2.4. Soil Clay Content

Mean soil clay content percentage values show a low clay content: 1.885% for roof 1; 2.484% for roof 2; 1.482% for roof 3; 9.779% for roof 4; 3.987% for roof 5; 2.596% for roof 6; 1.244% for roof 7 (Table A4). There is a much higher mean soil clay content for roof 4, but this still represents a low soil clay content. Since the range of soil clay content values is not large and they are all representative of a low clay content, even where there is a higher within roof variability seen with the coefficient of variation, in the context there is little within roof variation in a way that would alter the characteristics of the soil: 0.139 for roof 1; 0.827 for roof 2; 0.546 for roof 3; 0.285 for roof 4; 0.156 for roof 5; 0.251 for roof 6; 0.058 for roof 7 (Table A4). Fig. 4 shows the soil clay content value distribution for each roof. Roofs 1 to 3, and 5 to 7 have small within roof variability despite high coefficients of variation for roofs 2 and 3 which are due to low clay percentages causing a change of a few percent in clay content to be a drastic percentage of change. Roof 4 has a larger within roof variability and a higher percentage clay content than the other roofs. All roofs have a low percentage of clay in the soil materials. Although all roofs show a low percentage clay content, the small within roof variability seen indicates that the clay content results have a strong relationship to the individual roof effects such as such as the green roof characteristics or activities occurring on the roof.

It makes sense to observe low clay contents in agricultural green roofs since clay particles are very small, they can become compact and they also have a high water retention ability (Taylor, 1948; Canadian Agricultural Services Coordinating Committee & Soil Classification Working Group, 1998). These properties of clay would therefore increase the weight of soil materials drastically. Weight restrictions on agricultural green roofs for structural integrity concerns, and high material costs to provide support capable of bearing heavier loads prevent the option of using high amounts of clay in soils (Peck & Kuhn, 2003). This is different from natural soils found in southern Ontario which have higher amounts of clay (Keele, 1924; Allen & Johns, 1960; Kodama, 1979; Canadian Agricultural Services Coordinating Committee & Soil Classification Working Group, 1998). Conventional agricultural fields in the region grown on natural soil beds and agricultural green roofs will vary dramatically on interactions and qualities involving clay.

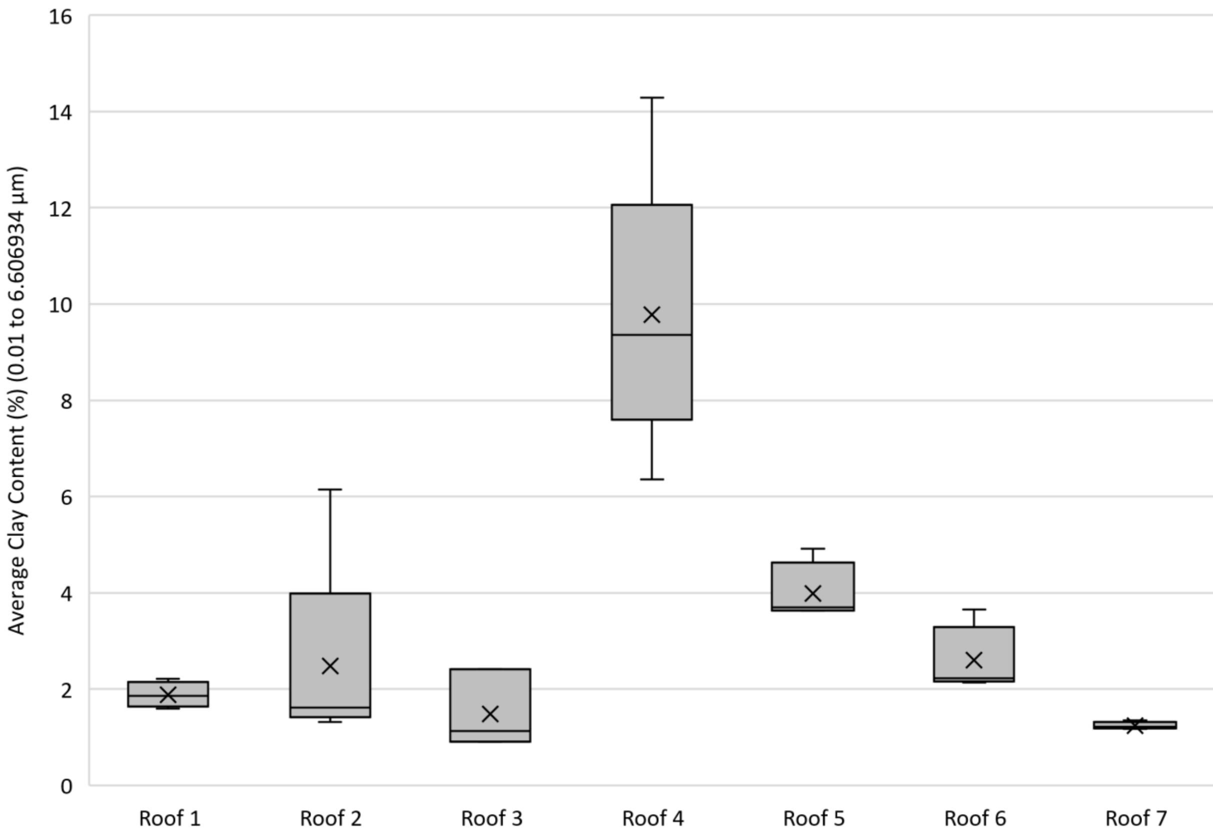

Fig. 4. Average clay content distribution of study plots for each study site.

4.2.5. Soil Total Nitrogen Content

Mean total nitrogen content percentage values are similar and do not show a high percentage, except for roof 4 which has a low total nitrogen percentage: Mean values of 0.99% for roof 1; 1.36% for roof 2; 0.95% for roof 3; 0.44% for roof 4; 1.03% for roof 5; 1.02% for roof 6; 1.10% for roof 7 (Table A5). There is little variation seen within each individual roof considering the small range of values for each roof: Coefficients of variation of 0.160 for roof 1; 0.234 for roof 2; 0.016 for roof 3; 0.238 for roof 4; 0.064 for roof 5; 0.099 for roof 6; 0.116 for roof 7 (Table A5). Fig. 5 shows the soil total nitrogen content value distribution for each roof. Roofs 1, and 3 to 7 have the smallest within roof variability. Roof 2 has a larger within roof variability. Roofs 1, 3, and 5 to 7 all have a similar total nitrogen content around one percent. Roof 2 has a higher range of total nitrogen content values than roofs 1, 3, and 5 to 7, while roof 4 has a low range of total nitrogen content values. Overall, all the total nitrogen values are within just over one percent of each other. The small within roof variability observed in the soil total nitrogen content results show a strong relationship to individual roofs, such as the green roof characteristics or activities occurring on the roof. Most of the total nitrogen in the soils sampled was in the form of organic nitrogen. Because the pools of organic nitrogen are so large compared to inorganic nitrogen, total nitrogen was used as an indicator of the amounts of nitrogen available in the soil matter materials in the analysis.

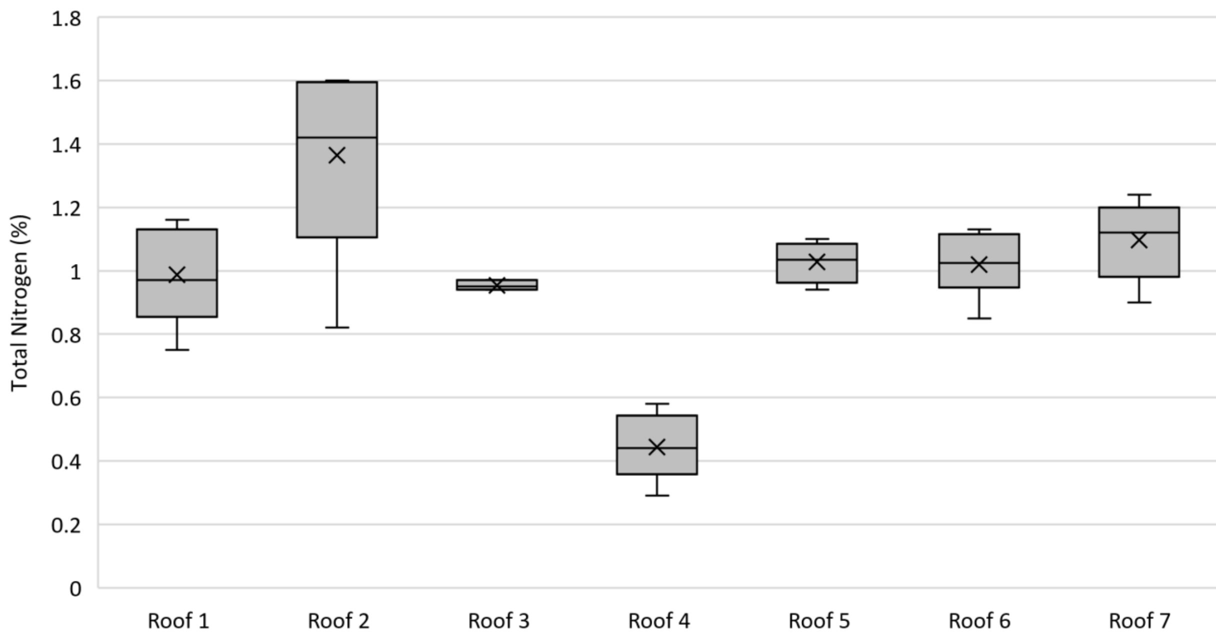

Fig. 5. Total nitrogen content distribution of study plots for each study site.

4.2.6. Soil Ammonium Content

Mean soil ammonium content values show high amounts of ammonium, except for roof 4 which has a lower amount of ammonium: 47.1 ppm for roof 1; 53.0 ppm for roof 2; 33.2 ppm for roof 3; 17.3 ppm for roof 4; 44.4 ppm for roof 5; 45.3 ppm for roof 6; 33.1 ppm for roof 7 (Table A6). There is a large amount of within roof variation seen for soil ammonium content for all roofs, except for roof 1 where little within roof variation is seen: Coefficients of variation of 0.041 for roof 1; 0.191 for roof 2; 0.201 for roof 3; 0.303 for roof 4; 0.200 for roof 5; 0.222 for roof 6; 0.239 for roof 7 (Table A6). Fig. 6 shows the soil ammonium content value distribution for each roof which matches with the within roof variabilities seen in the descriptive statistics. Roof 1 has a small within roof variability. Roofs 2 to 7 have a larger amount of within roof variability. As seen with roof 2 having the highest range of total nitrogen content values, it also has the highest range of ammonium content values. There is a high amount of overlap in the value ranges for roofs 1, 2, 5, and 6, which have the highest soil ammonium content values. There is a high amount of overlap in the value ranges for roofs 3 and 7, which have lower soil ammonium content values than roofs 1, 2, 5, and 6. Roof 4 has the lowest value range. The small within roof variability seen in the results for soil ammonium content show that roof 1 values have a strong relationship to roof effects such as such as the green roof characteristics or activities occurring on the roof. The larger within roof variability for roofs 2 to 7 show that the relationship between soil ammonium content and roof effects is not as great as seen with roof 1, and that other factors not related to the green roof characteristics or activities occurring on the roof are influencing the results.

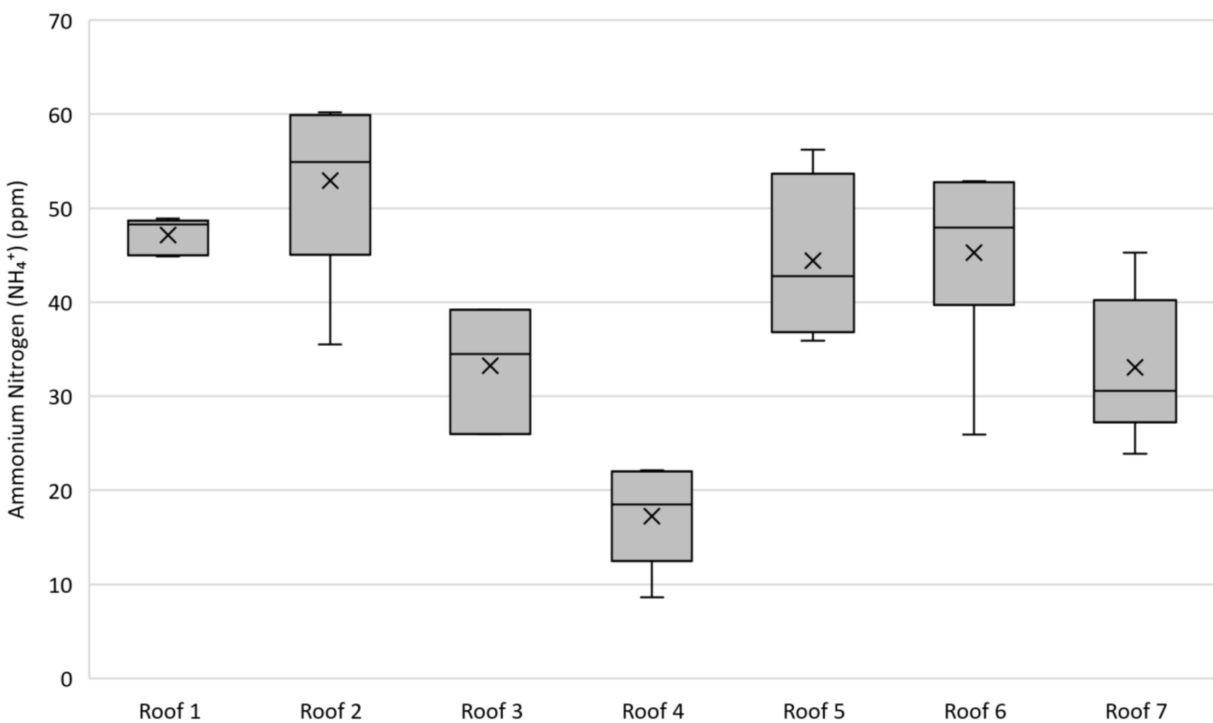

Fig. 6. Ammonium content distribution of study plots for each study site.

4.2.7. Soil Nitrate Content

Mean soil nitrate content values show low amounts of nitrate for roofs 3 and 4, moderate amounts for roofs 1, 5, 6, and 7, and a very high amount of for roof 2: 12.7 ppm for roof 1; 63.5

ppm for roof 2; 3.2 ppm for roof 3; 5.8 ppm for roof 4; 20.5 ppm for roof 5; 19.2 ppm for roof 6; 8.1 ppm for roof 7 (Table A7). The coefficients of variation are 0.906 for roof 1; 0.770 for roof 2; 0.185 for roof 3; 0.609 for roof 4; 0.496 for roof 5; 0.729 for roof 6; 0.271 for roof 7 (Table A7). There is a very high amount of within roof variation for roofs 1, 2, 5, and 6 (Table A7). Although there is also a very high coefficient of variation for roof 4, the range of values is not as large as with roofs 1, 2, 5, and 6, so the within roof variability is not as high (Table A7). There are also higher coefficients of variation (not as high as for the other roofs) for roofs 3, and 7, but the actual range of values is not large and there is small within roof variability (Table A7; Fig. 7). Fig. 7 shows the soil nitrate content value distribution for each roof. Roofs 3, 4 and 7 have small within roof variability. This is not what is seen with the descriptive statistics for roof 4 which indicate a high within roof variability. The values for roof 4 are all within the low soil nitrate content range, so the within roof variability, although statistically large, is small within the spectrum. Roofs 1, 2, 5, and 6 have larger within roof variability than roofs 3, 4, and 7. Roof 2 has a very high amount of within roof variability. Roofs 3, 4 and 7 have the lowest value ranges and overlap each other largely. Roof 1 has a higher range of values than roofs 3, 4, and 7, and partially overlaps the range for roofs 3, 4, and 7 and the range for roofs 2, 5, and 6. Roofs 5, and 6 have a range of values that overlap each other largely and which are higher than roofs 1, 3, 4, and 7, and partially overlap the ranges of roofs 1, 2, 4, and 7, and on their higher end roof 2. Roof 2 has the highest range of values for nitrate, just as it does for total nitrogen content and ammonium content. The small within roof variability seen in the results for soil nitrate content shows that values for roofs 3, 4, and 7 have a strong relationship to individual roof effects such as the green roof characteristics or activities occurring on the roof. The larger within roof variability seen with the soil nitrate content values for roofs 1, 2, 5, and 6 shows that the relationship between soil nitrate content results and individual roof effects are not as great as seen with roof 3, 4, and 7. For roof 2, the results show very little of the results for nitrate values can be attributed to individual roof effects.

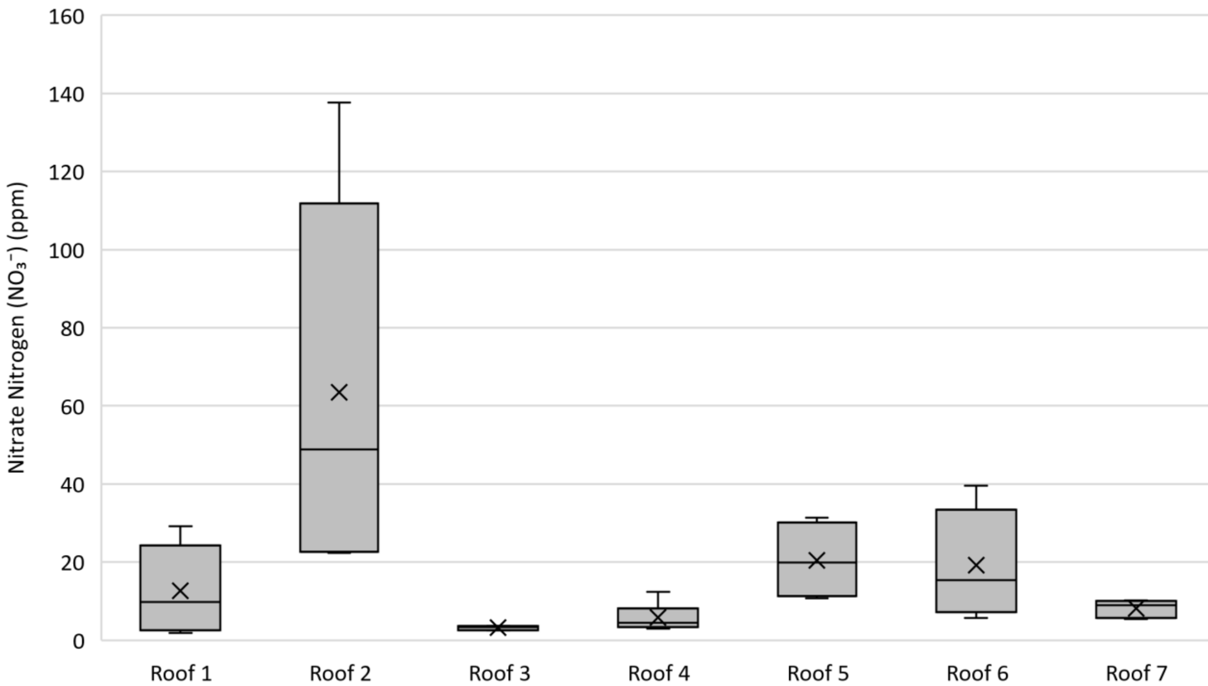

Fig. 7. Nitrate content distribution of study plots for each study site.

4.2.8. Earthworm Count

Mean earthworm count values show a low number for roofs 1, 3, and 4, a higher number for roof 7, and the highest numbers for roofs 2, and 6 while there were no earthworms found on roof 5: 0.6 for roof 1; 20.2 for roof 2; 1.0 for roof 3; 1.0 for roof 4; 0 for roof 5; 10.8 for roof 6; 4.4 for roof 7 (Table A8). All the roofs show a high within roof variation (except roof 5 where no earthworms were found), which can become high easily especially with lower numbers since 1 or 2 individuals can lead to a large difference between plots: Coefficients of variation of 1.491 for roof 1; 0.612 for roof 2; 1.732 for roof 3; 1.265 for roof 4; 0 for roof 5; 1.284 for roof 6; 1.166 for roof 7 (Table A8). Fig. 8 shows the earthworm count value distribution for each roof. There were no earthworms found on roof 5. Roofs 1, 3, and 4 have small within roof variability. Roof 7 has a higher amount of within roof variability than roofs 1, 3, and 4. Roofs 2 and 6 have a large amount of within roof variability. Roofs 1, 3, and 4 earthworm count results indicate a relationship to the individual roof effects such as characteristics and activities. The larger within roof variability seen in the earthworm count results for roofs 2, 6, and 7 indicate that the relationship between results and individual roof effects such as such as the green roof characteristics or activities occurring on the roof is weaker and that other factors are influencing the results.

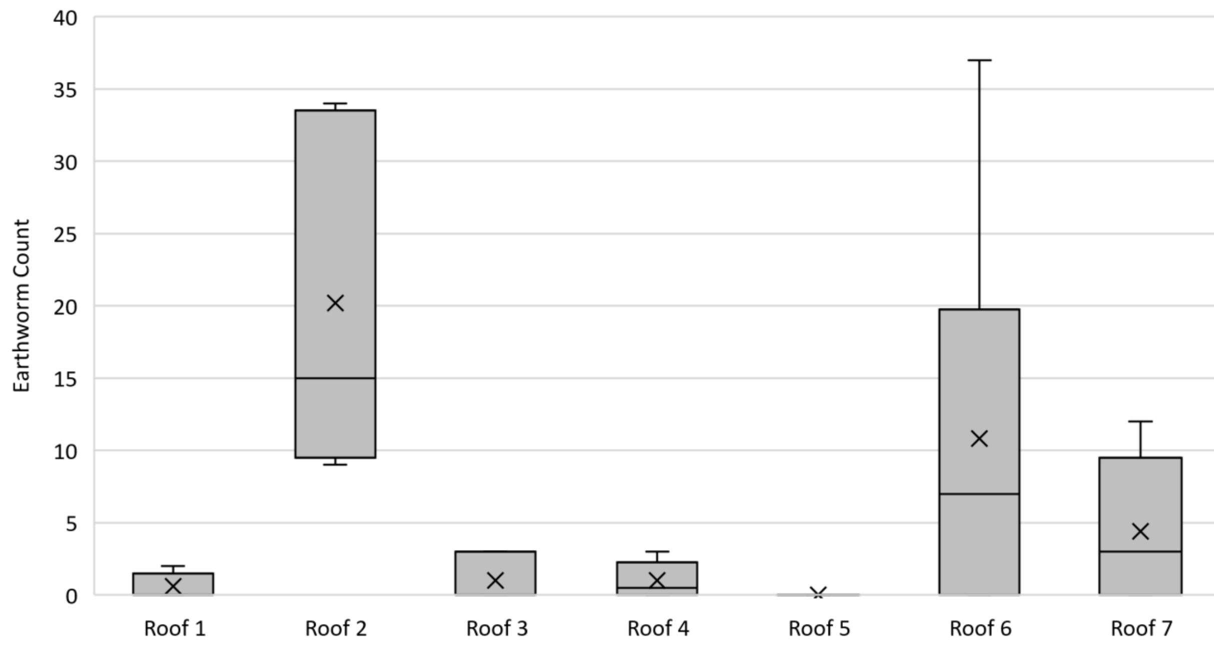

Fig. 8. Earthworm count distribution of study plots for each study site.

5. Discussion

5.1. Eisenia eiseni and Eisenia fetida

All the earthworms found in this study were identified to the lowest possible taxonomic identification as either *Eisenia eiseni* or *Eisenia fetida*, which are both epigeic earthworms. This supports with the hypothesis that epigeic earthworms were expected to be amoung the types of earthworms found, and anecic earthworms were not. However, no endogeic earthworms were amoung the earthworms found, so no support for their possible presence in agricultural green roofs is presented in this study. The earthworms are more likely *Eisenia fetida* since they are commonly used in vermicompost applications which are a common application in agriculture, including most of the agricultural green roofs in this study (Tripathi & Bhardwaj, 2004; Römbke et al., 2005; Siddique et al., 2005; Addison, 2009; Eijsackers, 2011). The *Eisenia eiseni* and *Eisenia fetida* earthworms are small, in this study the contracted lengths measured between 1.1cm and 4.6cm. *Eisenia eiseni* and *Eisenia fetida* have a red pigmentation over their whole body. The characteristic yellow banding in the intersegmental grooves that indicates *Eisenia fetida* species of earthworms was not found, however this will not always be present and can only confirm and not exclude the earthworm identity as being *Eisenia fetida,* especially with juveniles (Hale, 2013).

Soil condition preferences of *Eisenia eiseni* and *Eisenia fetida* earthworms can be expected to further define the original hypothesis of this study involving when earthworms are expected to be found, and when they are expected to be deterred. Conditions matching the preferences of *Eisenia eiseni* and *Eisenia fetida* are expected to be associated with the presence and increase in earthworm populations, and conditions outside of these preferences are expected to be associated with a decrease or absence of earthworm presence. The range of pH values preferred by *Eisenia eiseni* and *Eisenia fetida* are similar, with both experiencing optimal conditions between weakly acidic and slightly above neutral pH, which is a pH range of about 5 to 9, with an optimal pH around 7 (Kaplan et al., 1980; Trigo et al., 1989; Tripathi & Bhardwaj, 2004; Römbke et al., 2005; Siddique et al., 2005; Addison, 2009; Eijsackers, 2011). The earthworm species most likely found in this study, *Eisenia fetida*, inhabit soils with a high soil water content with preferences studied to begin closer to 60% and end shortly after 80%, after which soils become water logged and anaerobic (Kaplan et al., 1980; Neuhauser et al., 1980; Reinecke & Venter, 1987; Tripathi & Bhardwaj, 2004; Siddique et al., 2005). A high level of organic carbon is the preferred environment for the earthworm species found, *Eisenia eiseni* or *Eisenia fetida*, especially the most likely species *Eisenia fetida* which is found in compost and manure (Römbke et al., 2005; Siddique et al., 2005; Addison, 2009; Eijsackers, 2011).

Epigeic earthworms do not burrow and therefore can not survive winter cold conditions through burrowing and insulating themselves in deeper soils (Holmstrup, 2003). Most earthworms are not tolerant of below freezing temperatures (Meshcheryakova & Berman, 2014). The cocoons of earthworms can possibly tolerate below freezing temperatures by making use of a dehydration mechanism and decreasing ice crystallization of their high water contents (Holmstrup, 2003; Meshcheryakova & Berman, 2014). Even though the most likely species found in this study, *Eisenia fetida* does have the ability to dehydrate their cocoons to levels similar to other earthworm's cocoons that can survive below freezing temperatures, *Eisenia fetida* cocoons have not been seen to survive temperatures below freezing (Meshcheryakova & Berman, 2014). It could be possible that the dehydration necessary to survive freezing temperatures could be lethal to *Eisenia fetida* earthworms (Holmstrup, 2003; Meshcheryakova & Berman, 2014). The earthworms found in agricultural green roof soils most likely would be reintroduced at some point during the growing season in seasons they are present since the earthworm populations and cocoons from the previous season would not survive over winter. To make use of epigeic earthworms in the agricultural green roofs soils, it would follow that each growing season populations would have to be actively introduced to the gardens. Although epigeic earthworms are the smallest ecological class of earthworms, they still increase the amount of bioavailable nitrogen in soils (Tripathi & Bhardwaj, 2004; Suthar, 2008; Kawaguchi et al., 2011). They do not increase the amount of bioavailable nitrogen in soils as high as larger anecic earthworms (Suthar, 2008). Aside from larger size of anecic earthworms compared to epigeic earthworms, differences which anecic earthworms display are differing microbial gut communities, and an increase in favourable habitat conditions and organic materials for decomposing microbes in their burrows (Suthar, 2008). These features are suspected to contribute to the increased bioavailable nitrogen associated with anecic earthworm presence compared to epigeic earthworms presence (Suthar, 2008).

5.2. Earthworm Presence in Agricultural Green Roofs

This section discusses the relationship between the parameters studied and the presence of earthworms in the agricultural green roof soils.

5.2.1. Soil pH

The pH values for all sample plots were neutral or close to slightly acidic. There is not a range of pH values within which *Eisenia eiseni* or *Eisenia fetida* earthworm presence should be deterred, pH values outside of 5 and 9, supporting the updated hypothesis based on the earthworms found (Fig. 9). Earthworm presence was hence not deterred by highly acidic or alkaline soils for the agricultural green roof soils sampled.

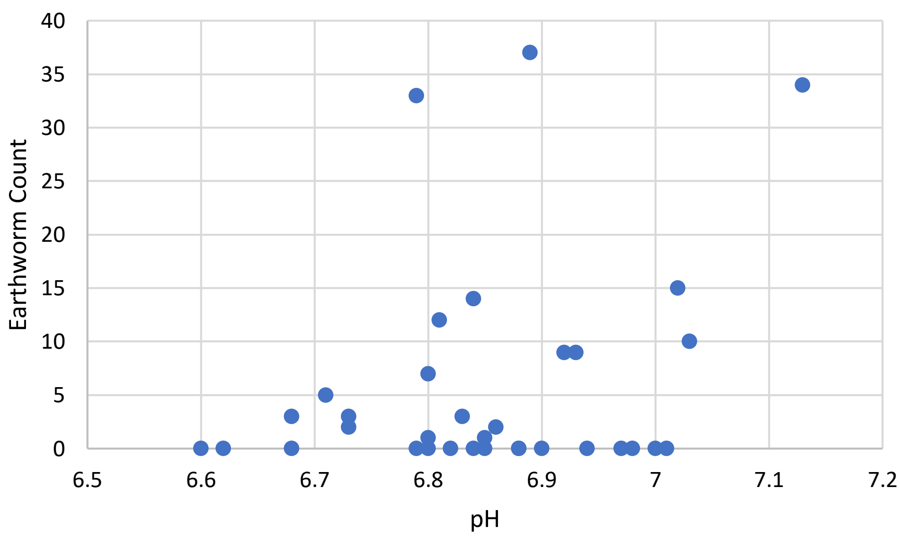

Fig. 9. Influence of soil pH on earthworm count at sampled study plots.

5.2.2. Earthworm Abundance Multiple Regression Analysis

A multiple regression analysis was performed to determine if the agricultural green roof soil parameters of soil water content, soil organic carbon content, soil depth, and soil total nitrogen content could predict the variation seen in earthworm abundance. The analysis produced a R square value (coefficient of determination) of 0.495, and a p-value of $< 1.0\text{x}10^{-4}$ (Table C.3a). This indicates that 49.5% of the variability seen with earthworm abundance can be explained by the remaining explanatory variables after analysis which are soil water content, soil organic carbon content, and soil depth, and that the relationship is statistically significant. The p-values at the end of analysis for each variable from the most to the least significant were $5.0x10^{-4}$ for soil water content, 0.011 for soil organic carbon content, and 0.018 for soil depth (Table C.3b). Soil total nitrogen content was not a significant predictor of earthworm abundance.

5.2.2.1. Soil Water Content

In the multiple regression model, soil water content was the most significant predictor of earthworm presence measured; p-value of $5.0x10^{-4}$ (Table C.3b). Low soil moisture contributes to the inability of earthworm populations to survive in agricultural green roof soils. On roof 5 this could have contributed to why earthworms were not found, the soils have increased drainage and had lower soil water contents (Table 9; Table 10). On roof 3 this could have contributed to why earthworms were not found at plots 3A and 3B because of a lower soil water content (Table 5). Plot 3C had a higher soil water content and earthworms were present (Table 5). This was possibly due to the growth of tomatoes at plot 3A and peppers at plot 3B which have a high-water requirement (Table 6). Plot 3C was highly shaded whereas plot 3A had no shade and 3B had partial shade which would lead to higher evaporation at lot 3A and 3B (Table 6). On roof 4 a low soil water content at all the study plots could have contributed to why there were a low amount, or no earthworms found at the study plots (Table 7). At several study plots throughout the study that made use of drip irrigation or similar systems there was a noticeably biased emergence of earthworms right next to or the closer the proximity to the water source. This further supports the results that earthworm presence in the agricultural green roofs studied was associated with whether there was a high enough water content in the soils. The soil water content preference of *Eisenia fetida* is around 60% to shortly after 80%, and this is what is seen in this study, earthworm populations increase once soil water content is close to 60% and remains higher at around 70% supporting the updated hypothesis based on the earthworms found (Fig. 10). The upper end of the preferred range of soil water content for *Eisenia fetida* was not seen in this study, so the affect of water logged soils on the earthworm populations was not observed here.

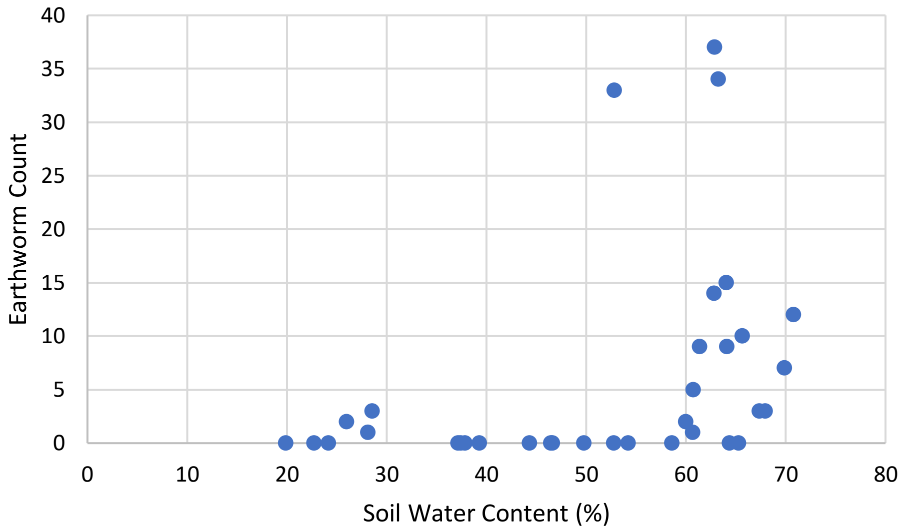

Fig. 10. Influence of soil moisture content on earthworm count at sampled study plots.

5.2.2.2. Soil Organic Carbon Content

Earthworm presence increased with increasing soil organic carbon content. In the multiple regression model, organic carbon content was the second most significant predictor of earthworm presence measured; p-value of 0.011 (Table C.3b). Most of the sampled agricultural green roof soils had high levels of organic carbon content which is the preference of the species found, *Eisenia eiseni* and *Eisenia fetida* (Fig. 11). The study plots on roof 4 had lower amounts of organic carbon possibly due to the limited soil renewal applications, which could have introduced a carbon limitation and a reduction in earthworm populations (Table 7; Fig. 11). For the other roofs there was plenty of organic material for earthworms to consume; there was not an organic carbon content limitation preventing earthworm populations from existing. What is seen here supports the updated hypothesis expectations based on the earthworms found. At roofs where there was a high enough organic carbon content available for earthworms, but where earthworms were not present, other factors could have prevented the earthworms from populating these soils (Fig. 11). Roof 1 is such a case, but there have been no known introductions of earthworms through use of earthworm castings, direct earthworm addition, or the use of vermicompost (Table 1; Table 2). Plots 3A and 3B on roof 3 also have high organic carbon contents but no earthworms were found, which could have been due to their lower soil water contents (Table 5). There is a similar situation at roof 5, which has high organic carbon content, but low soil water content and no earthworms (Table 9). Plots 6B and 6E on roof 6 also have high organic carbon contents, but low soil water contents, and no earthworms present (Table 11). Plots 7C and 7D on roof 7 have high organic carbon content, and have a high soil water content, but earthworms are still not present at these plots even though earthworms are found at the other plots on this roof; 7A, 7B, and 7E (Table 13). There is some drip irrigation at plots 7A, 7B, and 7E along with irrigation from oscillating sprinklers, however at plots 7C and 7D there is no drip irrigation and only oscillating sprinklers as a supplemental source of irrigation aside from rain (Table 14). The frequency of irrigation with the oscillating sprinklers (unknown) could be affecting the ability of earthworms to inhabit this soil, whereas drip irrigation has the ability, depending on operator usage, to efficiently keep soil water conditions moist more consistently (Table 14).

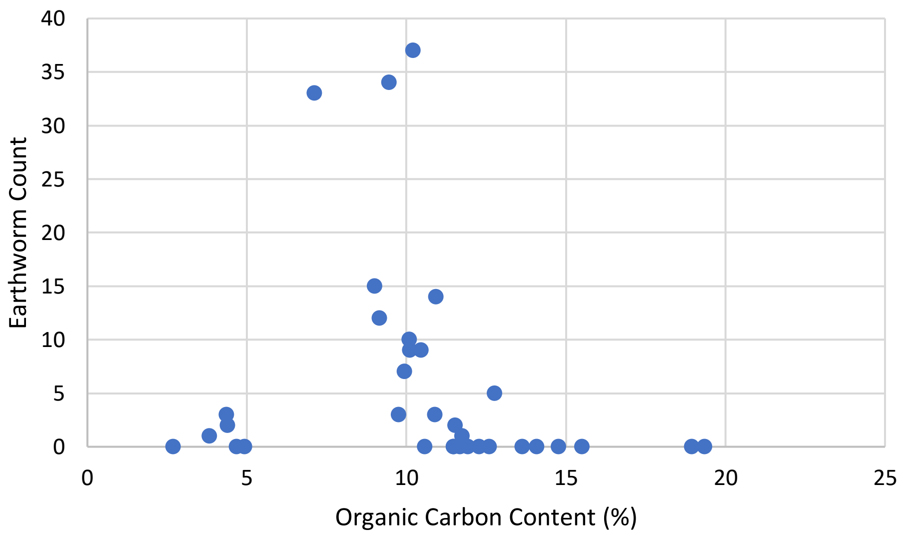

Fig. 11. Influence of soil organic carbon content on earthworm count at sampled study plots.

5.3. Factors Influencing Ammonium in Agricultural Green Roofs

This section discusses the relationship between the parameters studied and ammonium in the agricultural green roof soils.

5.3.1. Earthworm Abundance and Ammonium Multiple Regression Analysis

A multiple regression analysis was performed to determine if earthworm abundance could predict variation seen in ammonium content considering the agricultural green roof soil parameters of soil water content, soil organic carbon content, soil total nitrogen content, and soil depth. The analysis produced a R square value of 0.965, and a p-value of $< 1.0x10^{-4}$ (Table C.4a). This indicates that 96.5% of the variability seen with ammonium content can be explained by the remaining explanatory variables after analysis which are soil water content, soil depth, and earthworms count, and that the relationship is statistically significant. The p-values at the end of analysis for each variable from the most to the least significant were $<1.0x10^{-4}$ for soil water content, $<1.0x10^{-4}$ for soil depth, and 0.051 for earthworm count (Table C.4b). Soil organic carbon content and total nitrogen content were not significant predictors of soil ammonium content.

5.3.1.1. Soil Water Content and Ammonium

In the multiple regression model, soil water content was the most significant predictor of earthworm presence measured; p-value of $<1.0x10^{-4}$, along with soil depth which had the same p-value. (Table C.4b). Soil water content in the soils sampled is associated with a higher soil ammonium content (Table C.4b; Fig. 12). Without enough water, soils are not as habitable to earthworms and microbes, and activity also slows down (Drury et al., 2003; Paul et al., 2003; Curtin et al., 2012). Increased water content can support increased earthworm populations and activity levels of earthworms as well as other decomposers allowing for more conversion of organically bound nitrogen to ammonium (Drury et al., 2003; Paul et al., 2003; Curtin et al., 2012). This relationship of an increasing soil ammonium content with increasing soil water content is seen in the results (Fig. 14). There is a plateau in this relationship however beginning around the 50 to 65 percent range (Fig. 14). This can be due to optimal soil water conditions being reached, and above which there could be anaerobic conditions increasing with increasingly flooded soils, since oxygen is not as soluble in water as it in in air, leading to a lower saturation of oxygen in the soils, but this condition was not clearly reached in this study (Drury et al., 2003; Paul et al., 2003; Curtin et al., 2012). Aerobic conditions are required for earthworms and other decomposers. Although the breakdown of organic materials to release ammonium is not exclusively aerobic, aerobic processes eventually start to decrease with the increased flooding of soils and the slower anaerobic processes may not keep the same rate of ammonium production (Drury et al., 2003; Paul et al., 2003; Curtin et al., 2012). Looking at the study plots which had a high soil water content and a high soil ammonium content 4 had no earthworms present (plots 1A, 1B, 6E and 7D), 4 had a low amount of earthworms present (plots 1C, 1D, 3C, and 7B), 1 had a moderate amount of earthworms present (plot 6C), and 10 had a high amount of earthworms (plots 2A, 2B, 2C, 2D, 2E, 6A, 6D, 6F, 7A, and 7E). The majority of these plots with a high water content and a high ammonium content had earthworms present;15 out of 19 plots. Additionally, anaerobic conditions would prevent the nitrification of ammonium into nitrate, maintaining ammonium pools in the soil.

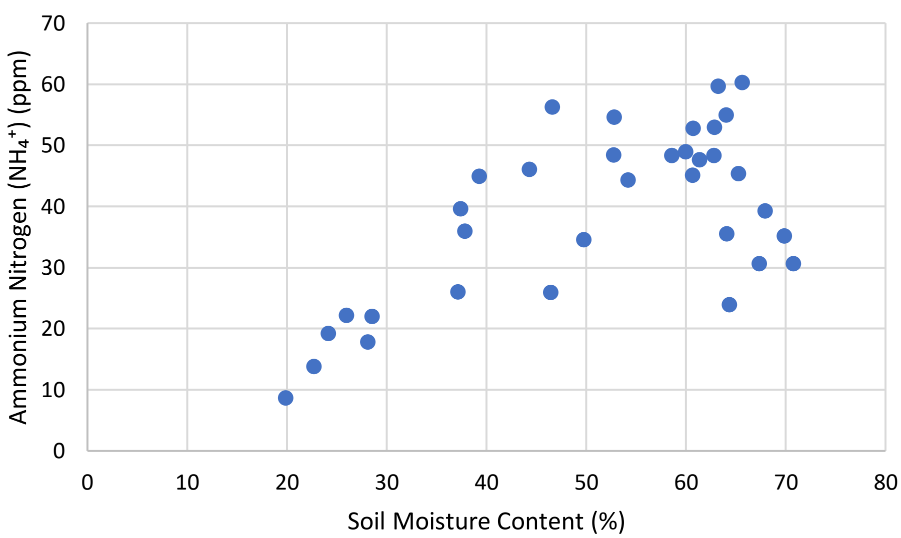

Fig. 12. Influence of soil moisture content on soil ammonium content at sampled study plots.

5.3.1.2. Earthworm Count and Ammonium

In the multiple regression model, earthworm abundance was a marginally-significant predictor of ammonium content and was the third most significant predictor measured; p-value of 0.051 (Table C.4b). This supports the hypothesis that an increase in ammonium will be seen with the presence of earthworms (Table C.4b; Fig. 13). This suggests that earthworm feeding, and egestion are breaking down organically bound nitrogen into ammonium increasing the amounts available to plants. There is not a consistent increase in ammonium with increasing number of earthworms however.

There is a small within roof variability in soil ammonium content on roof 1 compared to the larger within roof variability for soil ammonium content seen for roofs 2 to 7 (Fig. 6). Roof 1 applied fertilizers and compost one or two times in the two most recent growing seasons. The latest application was in late September of the sampling year, 2015. This would have led to an increased ammonium level. There were only a couple of earthworms found at plots 1C and 1D, indicating low presence and less attribution of any increase in nitrogen inputs to their activities.

Roof 2 applies compost and earthworm castings annually. The agricultural green roof actors involved with maintaining the gardens on roof 2 have observed earthworm presence in all the agricultural green roof gardens on the roof. This is supported by the results of this study which found an abundance of earthworms at every study plot. The ammonium levels were high at every study plot which results indicate has a positive relationship to earthworm's activities, and to the inputs to the soil every growing season.

Roof 3 applies additional soil mixes containing fertilizers every year, and applied compost during the 2015 growing season. Study plots 3B and 3C had notably high ammonium levels, with plot 3C having the highest, and being the only study plot on roof 3 where earthworms were found. Earthworms activities can be contributing to increased ammonium levels here compared to the other 2 study plots where earthworms were not found.

Roof 4 does not have high ammonium levels; however, there are the highest ammonium levels at study plots 4C, 4E, and 4F which are the plots where earthworms have been found. The exception is study plot 4B which has similar level of ammonium to plots 4C, 4E, and 4F. This may be attributed to legumes being grown in this area which can fix nitrogen and increase the nitrogen levels in the soil. It can also be noted that the gardens at study plots 4C, 4E, and 4F were constructed more recently than the gardens at study plots 4A, 4B, and 4D indicating a combination of increased nutrients in the newer soils, and decreased ability for earthworms to survive overtime leading to the resulting ammonium level patterns seen at this roof.

On roof 6 study plots 6A, 6C, 6D, 6E, and 6F all have high levels of ammonium. At these study plots, except for plot 6E, earthworms were present, with an abundance of earthworms present at plots 6A, 6D, and 6F. These results support a positive relationship to earthworm's activities and increased ammonium. Since plot 6E is used to grow tomatoes, carrots and eggplants which have high nutrient needs, maintenance may require additional nutrient inputs to soil to keep the plants yielding fruit and this may lead to the similar levels of ammonium here compared to the other plots where earthworms were found. Plot 6B does not have a high level of ammonium but the level of ammonium here is not low either, which may be attributed to the growth of legumes in this area which fix nitrogen and can increase the nitrogen levels in the soil.

Roof 7 has high levels of ammonium at plots 7A, 7B, 7D, and 7E. With the exception of plot 7D, earthworms were found at these study plots with an abundance of earthworms at plots 7A. These results show a positive relationship between earthworms and increased ammonium levels. Study plot 7D did however have the highest ammonium level for roof 7, the soil amendments made are unknown but may have influenced this result. Earthworms sampling may not have emerged all earthworms from the study plots, and earthworms habiting the general area and that may be influencing ammonium levels may move in and out of the area.

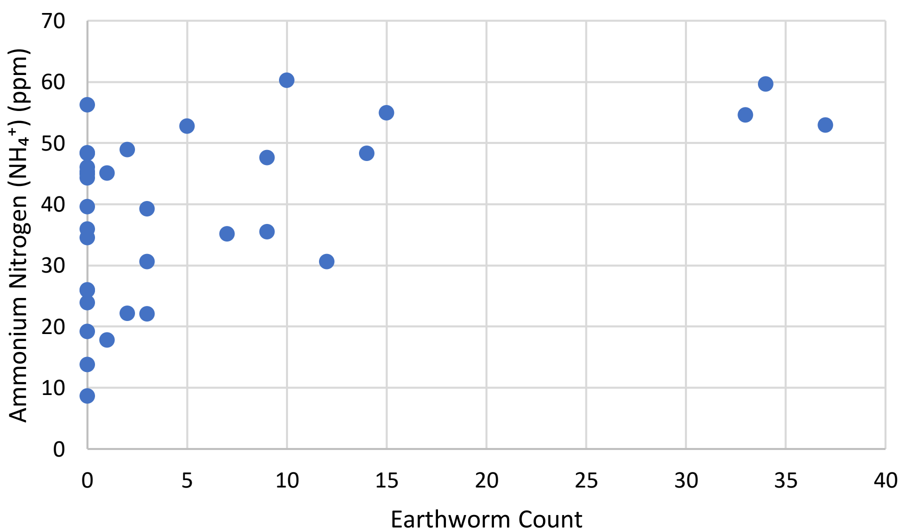

Fig. 13. Influence of earthworm count on soil ammonium content at sampled study plots.

5.3.2. Clay Content and Ammonium

Regression statistics for the relationship between soil clay content and soil ammonium content produces a R square value of 0.336, a F statistic of 16.210, and a p-value of 3.254×10^{-4} (Table C.1a; Table C.1b). Results show that there is a statistically significant relationship between clay content on ammonium content. It is seen that there is a decreasing amount of ammonium with an increasing clay content (Fig. 14). This is not what would be expected, since the clay will bind ammonium ions holding them in the soil (Kothawala & Moore, 2009). The range of soil clay content values still amount to a low level of clay in the spectrum, so the limited view of the relationship over the spectrum may mask the true relationship.

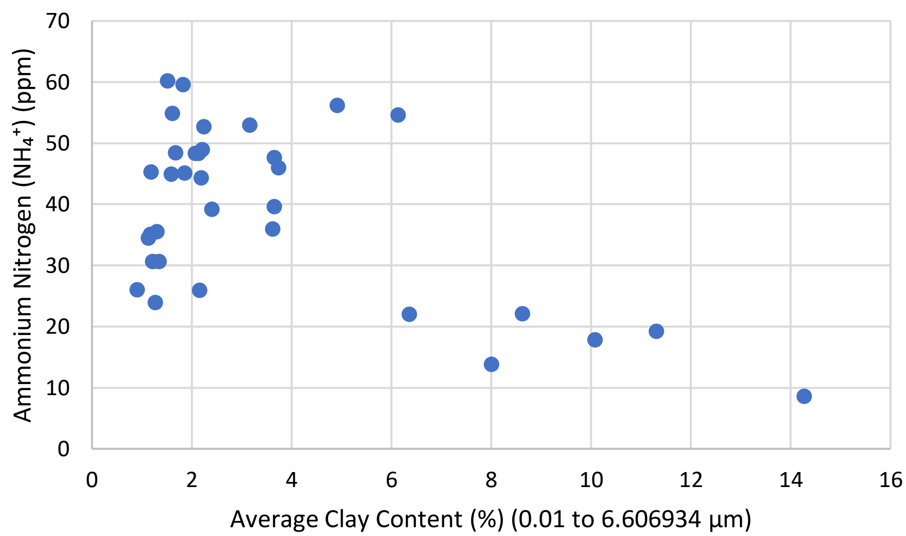

Fig. 14. Influence of clay content on soil ammonium content at sampled study plots.

5.4. Factors Influencing Nitrate in Agricultural Green Roofs

This section discusses the relationship between the parameters studied and nitrate in the agricultural green roof soils.

5.4.1. Earthworm Abundance and Nitrate Multiple Regression Analysis

A multiple regression analysis was performed to determine if earthworm abundance could predict variation seen in nitrate content considering the agricultural green roof soil parameters of soil water content, soils organic carbon content, soil total nitrogen content, soil ammonium content, and soil depth. The analysis produced a R square value of 0.746, and a p-value of $<1.0 \times 10^{-4}$ (Table C.5a). This indicates that 74.6% of the variability seen with soil nitrate content can be explained by the remaining explanatory variables, soil water content, soil organic carbon content, and soil total nitrogen content, and that the relationship is statistically significant. The p-values at the end of analysis for each variable from the most to the least significant were $<1.0 \times 10^{-4}$ for soil total nitrogen content, 3.0×10^{-4} for soil organic carbon content, and 2.8×10^{-3} for soil water content (Table C.5b). Earthworm count, soil ammonium content, and soil depth were not significant predictors of soil nitrate content.

5.4.1.1. Soil Water Content and Nitrate

In the multiple regression model, soil water content was the third most significant predictor of nitrate content measured; p-value of 2.8×10^{-3} (Table C.5b). Increasing soil water content in the soils sampled is associated with a higher soil nitrate content (Table C.5b; Fig. 15). This is possibly in response to the relationship seen with ammonium, an increasing ammonium content with increasing soil water content, with additional ammonium being available as a source for nitrification. However, ammonium was removed as an explanatory variable for what is seen with nitrate content in the multiple variable analysis. Increases in aerobic activity with increased soil water content (before water logged, anaerobic soils occur) mentioned previously may also be contributing to the increased nitrate content seen with increasing soil water content (Drury et al., 2003; Paul et al., 2003; Curtin et al., 2012).

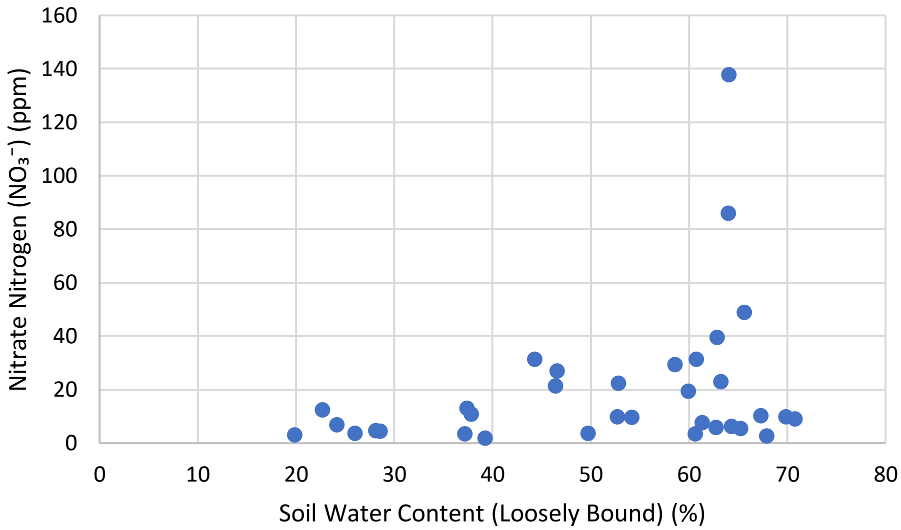

Fig. 15. Influence of soil moisture content on soil nitrate content at sampled study plots.

5.4.1.2. Total Nitrogen and Nitrate

In the multiple regression model, soil total nitrogen content was the most significant predictor of nitrate content measured; p-value of $<1.0 \times 10^{-4}$ (Table C.5b). Increasing soil total nitrogen content in the soils sampled is associated with a higher soil nitrate content (Table C.5b; Fig. 16). This could indicate that nitrogen inputs to soils are attributing to increased amounts of nitrate produced due to more source materials.

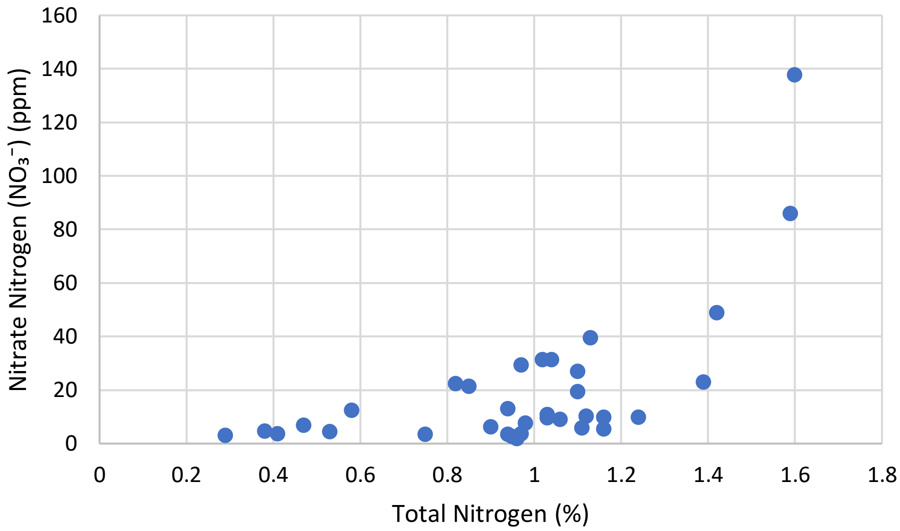

Fig. 16. Influence of soil total nitrogen content on soil nitrate content at sampled study plots.

5.4.1.3. Ammonium and Nitrate

Although ammonium is a source of nitrate the increase in nitrate seen with an increase in ammonium is not statistically significant (Fig. 17). There are many reasons which could be masking this relationship. Ammonium may not be transforming into nitrate either because the rate of nitrification is not significant enough to see this translation, or anaerobic conditions could be preventing nitrification. Ammonium can be taken up by plants and removed from the soil before it is transformed to nitrate. Additionally, if the ammonium is being converted into nitrate, the nitrate can be accumulating in the soils in large amounts, obscuring the increases in nitrate associated with increases in ammonium. Several sites had high levels of nitrate where this could have been the case. Opposite to this, the nitrate could be being removed through plant's preferential uptake of nitrate compared to ammonium, drainage and leaching, or through denitrification in anaerobic conditions due to high amounts of water, or low permeability of soils. In the same ways the association between ammonium and nitrate were not seen in here, the relationship between earthworm's activities and increased nitrate content in soils would be obscured. It is through ammonium production and subsequent conversion to nitrate through nitrification that the influence that earthworms have on nitrate content takes place. Dynamics in nitrogen cycling make measurement of exact transformations difficult without continuous measurement of different nitrogen products.

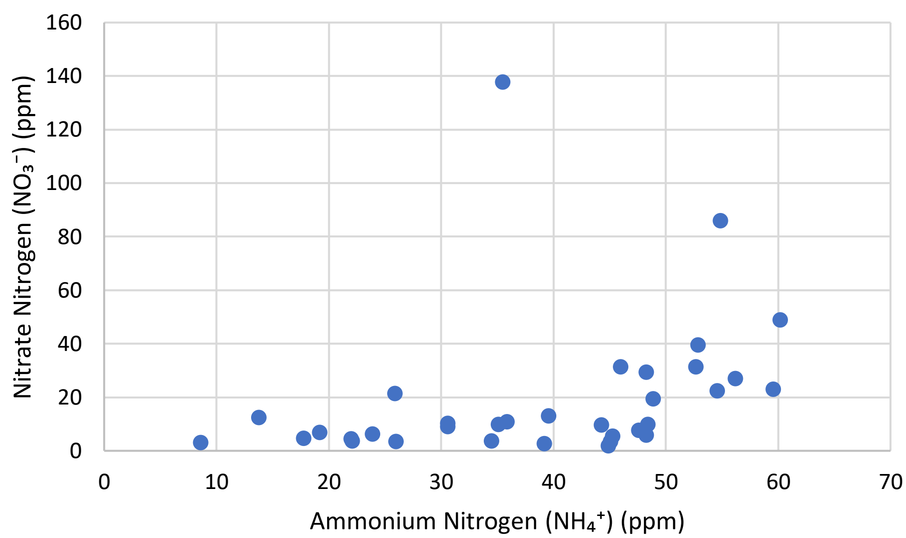

Fig. 17. Influence of soil ammonium content on soil nitrate content at sampled study plots.

5.4.2. Clay Content and Nitrate

Regression statistics for the relationship between soil clay content and soil nitrate content produces a R square value of 0.051, a F statistic of 1.736, and a p-value of 0.197 (Table C.2a; Table C.2b). Results show that there is no statistically significant relationship of clay content on nitrate content which would exist through the higher water retention of clay and less leaching of nitrate with water drainage through soil (Taylor, 1948; Canadian Agricultural Services Coordinating Committee & Soil Classification Working Group, 1998). There is the same relationship seen with nitrate as is seen with ammonium: a decreasing amount of nitrate with increasing soil clay content (Fig. 18). This could be a result of less ammonium seen with higher clay content, and hence less source nitrogen for nitrification. An increasing clay content could also decrease diffusion potential of oxygen into soils due to less porosity, and this could decrease aerobic nitrification and production of nitrate, and increase anaerobic denitrification and conversion of nitrate to gaseous nitrogen species. This could also contribute to the decreasing ammonium content seen with an increasing clay content; instead of leading to an increase in ammonium content, the lower production and higher removal of nitrate from the soil could be leading to and increased uptake of ammonium by plants due to lower pools of nitrate, decreasing the soil ammonium content. The range of clay content values is still low, so the influence of clay content on what is seen with ammonium content and nitrate content in the soils would not be extensive.

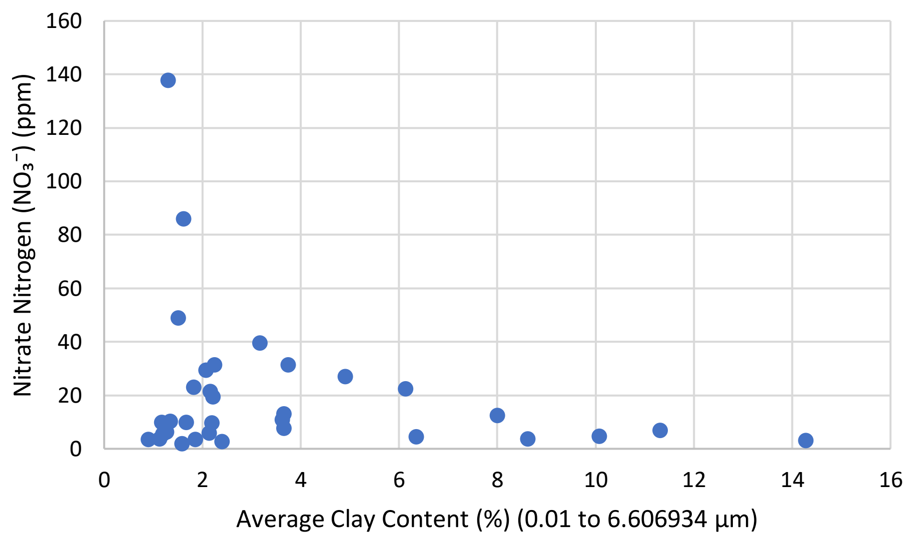

Fig. 18. Influence of clay content on soil nitrate content at sampled study plots.

5.5. The Idea of a Micro Habitat

Epigeic earthworms are smaller than endogeic and anecic earthworms, and hence their inputs to soil through egestion is smaller (Suthar, 2008). Conventional agricultural fields are grown on natural soils which have depths greater than agricultural green roof soils, and have both organic and mineral soil horizons (Angers et al., 1997; Carter et al., 1997; Harrison et al., 2011). Various soil components including ammonium and nitrate pool and distribute through this larger volume of agriculture field which has a larger amount of material and holding capability (Angers et al., 1997; Carter et al., 1997; Harrison et al., 2011; Hill, 2011). Agricultural green roofs are shallow in comparison due to weight, material, and financial restrictions (Peck & Kuhn, 2003). The soils on agricultural green roofs therefore resemble more closely the shallow top layers of soils, mainly the organic layers. Epigeic earthworms do not create permanent burrows, so the main benefits to soil fertility from their presence in agricultural green roof soils is related to their feeding, and egestion increasing the ammonium content in the soil (Suthar, 2008). The inputs of these epigeic earthworms may be diluted in large volumes of soil in conventional agricultural fields, where large populations of epigeic earthworms would be needed to produce an influential effect. In the agricultural green roof soils, the number of epigeic earthworms found were associated with statistically significant increases in bioavailable nitrogen in the form of ammonium in the soils. The volumes of soil here are much less than in conventional agricultural fields, so inputs into the soil do not become as diluted, and fewer inputs can therefore produce stronger effects than they would in a large agricultural field. The shallow soils in agricultural green roofs also restrict the ability of many earthworms to inhabit these soils due to their behaviours and habitats requiring deeper soils, but this habitat trait is well suited to epigeic earthworms. This leads to the idea that this micro habitat can support micro populations of earthworms, and in turn these micro populations of earthworms can provide inputs which match the scale of the environment they are in. The smaller the environment, the more sensitive it is to small changes (Oberndorfer et al., 2007; Buffam & Mitchell, 2015). The different categories of parameters are more easily fluctuated between, as the amounts required to change the measurements decreases (Oberndorfer et al., 2007; Buffam & Mitchell, 2015). The increased bioavailable nitrogen associated with epigeic earthworms seen in the results here could be providing bioavailable nitrogen capable for meeting the nutritional needs of the plants grown in agricultural green roof soils. In order to precisely define the magnitude of this possibility, further study into the bioavailable nitrogen input associated with these earthworms, and the rise in soils and plant yields associated with different amounts of inputs from these earthworms would need to be quantified.

6. Limitations

This was not a longitudinal study, sampling took place on a single date for each study site. The sampling was done in the Fall of 2015, the time period between September 2015 to the beginning of November 2015. The results are static and do not show dynamics or long-term patterns. The results also show measurements for the near end or end of the growing season for agricultural crops. The end of the growing season is a time after a growing season of plant uptake of nutrients from soils, and permanent removal through harvesting of crops. No sampling was done during a spring growing season which is the other time that earthworm activity is high. Spring is also the beginning of the growing season, before a long period of plant removal of nutrients from the soils.

In order to see what the agricultural green roofs status was, a field study approach was employed. Carrying out a field study was ideal for the exploratory approach taken to observe the concepts of concern in a setting where they have not been studied. The extent of extrapolation of the relationships between the variables studied from other environments to agricultural green roofs is unknown and will not be quantified fully here. This study looked at whether there is a positive association between earthworms and bioavailable nitrogen in the agricultural green roof setting as has been seen to exist elsewhere including in agricultural practices. This study also looked at other factors at the agricultural green roofs that are possibly contributing to what is seen with earthworm presence, bioavailable nitrogen levels, and the association between them. Controlled laboratory experiments to further define the exact nature of the relationships being observed are a future endeavour which can benefit from accurate information about the agricultural green roof conditions that are seen in the current applications and insight about whether the relationships examined are supported in this setting and what may be contributing to this.

The amount of study plots depended on the access to the roof. Site visits needed to be coordinated on a day meeting the study criteria, and during a time where someone could provide access to the roof and secure the roof after the visit. There was more time available to sample certain study sites than others due to people's schedules, especially if the visits required supervision. This led to the ability to sample more study plots from some study sites when the site visit was longer, than others where the visits were shorter.

There were some concerns about sampling earthworms and soils from the agricultural green roofs from the actors involved including over invasive removal of soil, and not wanting to remove earthworm populations from the soils permanently. These concerns had to be considered in determining which methods were used for the study. Some earthworms had to be identified on site during the visit, with pictures taken for later reference, so the earthworms cold be returned to the soils after. The soils were shallow, and within the 35 cm by 35 cm study plots a large amount of soil could not be removed for analysis so as not to be too invasive to the gardens. This affected what field and laboratory methods could be used, and at times including particle size analysis, ammonium testing, and nitrate testing, methods requiring smaller amounts of soil were favoured compared to methods requiring larger amounts of soil.

Soil depths within the study plots were estimated by the average of the depths of the soil cores taken within the plot. Depths not only varied between roofs, but within a study plot, and between study plots on the same roof. The volumes of soil were not measured in this study. Earthworm count data in this study therefore was not corrected for by soil volume differences.

Agricultural green roofs to be included in the study were limited not only by the study site characteristics criteria, but also to the agricultural green roofs where contacts could be reached, and visits arranged during the field work time period. Some agricultural green roofs could not be sampled because the correct contacts could not be reached to arrange access to the gardens. This also affected the information that could be gathered about the agricultural green roofs during the survey since some actors did not have access to all the information asked about or could not be reached about completing the full survey during the study period. The agricultural green roof actors vary in how closely they work with the gardens and knowledge about activities and maintenance in the gardens. Some agricultural green roofs actors also made use of more involved practices and assessments than others, applying more tailored techniques to meet the needs of specific gardens than others. Information was more readily available in some cases compared to others. Specific information about nutrient loadings was not available for all the study sites. Exact amounts of ammonium and nitrate that can be attributed to certain sources were not able to be determined. It was not possible to determine exact amounts of ammonium and nitrate sourced from the breakdown of organic materials associated with earthworm activity.

A longer term study monitoring the amount of nitrogen from different sources and transformations in soils would need to be undertaken to obtain quantifiable amounts.

7. Conclusion

7.1. Earthworms Establishment in Agricultural Green Roof Soils

Earthworms were found in the agricultural green roof soils of all the roofs studied except for roof 5. Some populations were found in low numbers, but some roofs had a high number of earthworms in the soils. Although theoretically possible for epigeic or endogeic earthworms to inhabit the soils of the green roofs based on soil depth, only epigeic earthworms were found. All earthworms found were either *Eisenia eiseni* or *Eisenia fetida*, which are commonly used in vermicompost (Tripathi & Bhardwaj, 2004; Römbke et al., 2005; Siddique et al., 2005; Addison, 2009; Eijsackers, 2011). This suggests that they came with the soil materials or through the vermicompost that some roofs have made use of. For the roofs studied there was no lack of organic carbon except for at roof 4 which could have introduced a carbon limitation for earthworms and contributed to the low number found on this roof. All soils had a pH that was neutral with the lowest values approaching slightly acidic. These conditions are supportive of the earthworms' found, *Eisenia eiseni* or *Eisenia fetida*, ability to inhabit these soils since it is within their pH preference of 5 to 9. The soils at roof 4 had lower organic carbon contents, and the pH measurement could be higher than the actual pH of the soil samples due to the 1:4 ratio applied for organic soils. Earthworm presence was strongly associated with soil water content. Soils with a low soil water content were seen to have a lower number or no earthworms and would have deterred earthworm presence in the soils studied. Shallow soils also could have deterred earthworm presence as there were less or no earthworms at some of these shallower sites. The conditions that deterred earthworm presence would need to be remedied if incorporating earthworms in agricultural green roof practices were to be applied successfully. Earthworm populations would need to be reintroduced each growing season if the earthworms found, *Eisenia eiseni* or *Eisenia fetida*, are being used as a method of improving nitrogen availability to plants since they do not survive successfully over winter (Meshcheryakova & Berman, 2014).

7.2. Earthworms and Bioavailable Nitrogen

Results showed an increased level of bioavailable nitrogen in the soils where earthworms are present, with a statistically significant higher ammonium level. Earthworms being associated with increased levels of ammonium was supported by the results of this study. Earthworms associated with increased levels of nitrate was not supported by this study. The practice of using earthworms in conventional agriculture, to increase soil fertility in terms of increasing the bioavailable nitrogen, could be a possibility in agricultural green roofs based on results but needs further study to better define how much of the inputs are due to earthworms. The extent of the benefits needs further exploration to determine if the amounts of bioavailable nitrogen provided by the practice of populating the soils with earthworms meets the needs of the plants. The higher ammonium levels did not always translate into higher nitrate levels which is the most readily available form of nitrogen to plants. Whether this is due to the successful uptake of nitrate by plants, the conditions preventing the conversion of ammonium to nitrate, high rates of ammonium removal from soils, or high nitrate pools obscuring the relationship can be investigated in the future.

7.3. Earthworms and Soil Fertility in Agricultural Green Roofs

The agricultural green roof soils are more confined than the soils of conventional agricultural fields in terms of depth and area coverage of the gardens. There were earthworms found in the agricultural green roof soils, but these were only smaller-sized earthworms from one ecological group and smaller populations than populations that can be supported in conventional agricultural fields with greater volumes of soils material. Although the total output of benefits is less from these smaller populations of earthworms, the soil habitat they are in is also much less expansive. In comparison to conventional agricultural fields, the idea arises that agricultural green roofs are like a micro-habitat hosting a micro-population of earthworms, with possibly less nutritional inputs required to maintain a fertile environment. What is known is that in some circumstances there is a possibility of supporting some amount of earthworm population in these agricultural green roofs soils, since their presence was widely seen in this study. Performing tests to determine if other earthworms would be able to survive in these soils would increase this knowledge. Results support that earthworms are associated with raised levels of bioavailable nitrogen in the soils of agricultural green roofs, but do not determine how much they contribute to this rise. The usefulness of applying this practice in agricultural green roofs requires further study to determine whether the inputs of bioavailable nitrogen from this application would be suitable to meet plant’s needs, require supplemental strategies in conjunction to reach nutritional goals, or are not efficient enough to have a meaningful impact on supporting plant life in the agricultural green roofs.

Appendices

Appendix A. Parameter Summary

Table A1 to Table A8 list the descriptive statistics of a single parameter for each roof.

A.1. pH

Table A1. Descriptive statistics summary of pH results for all study sites.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
Roof 1	6.60	6.86	6.68	6.71	0.11	0.017	1.693
Roof 2	6.79	7.13	7.02	6.98	0.13	0.018	1.845
Roof 3	6.73	7.01	6.88	6.87	0.14	0.020	2.039
Roof 4	6.73	7.00	6.82	6.83	0.10	0.013	1.337
Roof 5	6.84	6.98	6.91	6.91	0.06	0.009	0.900
Roof 6	6.71	6.93	6.87	6.85	0.08	0.011	1.133
Roof 7	6.68	6.97	6.81	6.82	0.10	0.015	1.513

A.2. Soil Water Content

Table A2. Descriptive statistics summary of soil water content (%) results for all study sites.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
Roof 1	39.285	60.672	58.595	54.257	8.932	0.165	16.463
Roof 2	52.846	65.681	64.051	61.987	5.185	0.084	8.364
Roof 3	37.187	67.940	49.758	51.628	15.462	0.299	29.948
Roof 4	19.884	28.551	25.101	24.916	3.327	0.134	13.353
Roof 5	37.451	46.606	41.105	41.567	4.602	0.111	11.070
Roof 6	46.463	62.876	61.069	58.085	6.530	0.112	11.241
Roof 7	64.369	70.792	67.345	67.533	2.798	0.041	4.144

A.3. Soil Organic Carbon Content

Table A3. Descriptive statistics summary of soil organic carbon content (%) results for all study sites.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
Roof 1	11.524	18.944	12.281	13.626	3.084	0.226	22.633
Roof 2	7.127	10.454	9.462	9.227	1.302	0.141	14.105
Roof 3	10.897	19.348	15.503	15.249	4.231	0.277	27.748
Roof 4	2.698	4.928	4.384	4.152	0.802	0.193	19.308
Roof 5	11.677	14.768	13.340	13.281	1.402	0.106	10.553
Roof 6	10.115	12.761	10.748	11.087	1.049	0.095	9.458
Roof 7	9.162	11.475	9.947	10.362	1.055	0.102	10.178

A.4. Soil Clay Content

Table A4. Descriptive statistics summary of soil average clay content (%) results for all study sites.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
Roof 1	1.594	2.218	1.860	1.885	0.262	0.139	13.914
Roof 2	1.311	6.141	1.618	2.484	2.053	0.827	82.663
Roof 3	0.905	2.408	1.133	1.482	0.810	0.546	54.631
Roof 4	6.360	14.282	9.355	9.779	2.789	0.285	28.520
Roof 5	3.627	4.915	3.702	3.987	0.621	0.156	15.583
Roof 6	2.139	3.657	2.224	2.596	0.653	0.251	25.147
Roof 7	1.175	1.353	1.221	1.244	0.072	0.058	5.802

A.5. Soil Total Nitrogen Content

Table A5. Descriptive statistics summary of soil total nitrogen content (%) results for all study sites.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
Roof 1	0.75	1.16	0.97	0.99	0.16	0.160	15.994
Roof 2	0.82	1.60	1.42	1.36	0.32	0.234	23.372
Roof 3	0.94	0.97	0.95	0.95	0.02	0.016	1.602
Roof 4	0.29	0.58	0.44	0.44	0.11	0.238	23.772
Roof 5	0.94	1.10	1.04	1.03	0.07	0.064	6.425
Roof 6	0.85	1.13	1.03	1.02	0.10	0.099	9.882
Roof 7	0.90	1.24	1.12	1.10	0.13	0.116	11.642

A.6. Soil Ammonium Content

Table A6. Descriptive statistics summary of soil ammonium content (NH_4^+) (ppm) results for all study sites.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
Roof 1	44.9	48.9	48.3	47.1	2.0	0.041	4.138
Roof 2	35.5	60.2	54.9	53.0	10.1	0.191	19.066
Roof 3	26.0	39.2	34.5	33.2	6.7	0.201	20.132
Roof 4	8.6	22.1	18.5	17.3	5.2	0.303	30.336
Roof 5	35.9	56.2	42.8	44.4	8.9	0.200	20.011
Roof 6	25.9	52.9	48.0	45.3	10.0	0.222	22.175
Roof 7	23.9	45.3	30.6	33.1	7.9	0.239	23.883

A.7. Soil Nitrate Content

Table A7. Descriptive statistics summary of soil nitrate content (NO_3^-) (ppm) results for all study sites.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
Roof 1	1.8	29.2	9.8	12.7	11.5	0.906	90.596
Roof 2	22.3	137.7	48.8	63.5	48.9	0.770	76.951
Roof 3	2.5	3.6	3.4	3.2	0.6	0.185	18.504
Roof 4	2.9	12.4	4.5	5.8	3.5	0.609	60.893
Roof 5	10.7	31.3	20.0	20.5	10.2	0.496	49.638
Roof 6	5.7	39.5	15.4	19.2	14.0	0.729	72.875
Roof 7	5.4	10.2	8.9	8.1	2.2	0.271	27.135

A.8. Earthworm Count

Table A8. Descriptive statistics summary of earthworm count (number of earthworms) results for all study sites.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
Roof 1	0	2	0	0.6	0.9	1.491	149.071
Roof 2	9	34	15.0	20.2	12.4	0.612	61.174
Roof 3	0	3	0	1.0	1.7	1.732	173.205
Roof 4	0	3	0.5	1.0	1.3	1.265	126.491
Roof 5	0	0	0	0	0	0	0
Roof 6	0	37	7.0	10.8	13.9	1.284	128.360
Roof 7	0	12	3,0	4.4	5.1	1.166	116.553

Appendix B. Roof Parameter Summary

Table B1 to Table B7 list the descriptive statistics for each parameter on a per roof basis for roof 1 to roof 7.

Table B1. Summary of parameters for roof 1.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
pH	6.60	6.86	6.68	6.71	0.11	0.017	1.693
Soil Water Content (Loosely Bound) (%)	39.285	60.672	58.595	54.257	8.932	0.165	16.463
Soil Organic Carbon Content (%)	11.524	18.944	12.281	13.626	3.084	0.226	22.633
Average Clay Content (%) (0.01 to 6.606934 µm)	1.594	2.218	1.860	1.885	0.262	0.139	13.914
Total Nitrogen (%)	0.75	1.16	0.97	0.99	0.16	0.160	15.994
Ammonium Nitrogen (NH_4^+) (ppm)	44.9	48.9	48.3	47.1	2.0	0.041	4.138
Nitrate Nitrogen (NO_3^-) (ppm)	1.8	29.2	9.8	12.7	11.5	0.906	90.596
Earthworm Count	0	2	0	0.6	0.9	1.491	149.071

Table B2. Summary of parameters for roof 2.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
pH	6.79	7.13	7.02	6.98	0.13	0.018	1.845
Soil Water Content (Loosely Bound) (%)	52.846	65.681	64.051	61.987	5.185	0.084	8.364
Soil Organic Carbon Content (%)	7.127	10.454	9.462	9.227	1.302	0.141	14.105
Average Clay Content (%) (0.01 to 6.606934 µm)	1.311	6.141	1.618	2.484	2.053	0.827	82.663
Total Nitrogen (%)	0.82	1.60	1.42	1.36	0.32	0.234	23.372
Ammonium Nitrogen (NH_4^+) (ppm)	35.5	60.2	54.9	53.0	10.10	0.191	19.066
Nitrate Nitrogen (NO_3^-) (ppm)	22.3	137.7	48.8	63.5	48.9	0.770	76.951
Earthworm Count	9	34	15	20.2	12.4	0.612	61.174

Table B3. Summary of parameters for roof 3.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
pH	6.73	7.01	6.88	6.87	0.14	0.020	2.039
Soil Water Content (Loosely Bound) (%)	37.187	67.940	49.758	51.628	15.462	0.299	29.948
Soil Organic Carbon Content (%)	10.897	19.348	15.503	15.249	4.231	0.277	27.748
Average Clay Content (%) (0.01 to 6.606934 µm)	0.905	2.408	1.133	1.482	0.810	0.546	54.631
Total Nitrogen (%)	0.94	0.97	0.95	0.95	0.02	0.016	1.602
Ammonium Nitrogen (NH_4^+) (ppm)	26.0	39.2	34.5	33.2	6.7	0.201	20.132
Nitrate Nitrogen (NO_3^-) (ppm)	2.5	3.6	3.4	3.2	0.6	0.185	18.504
Earthworm Count	0	3	0	1.0	1.7	1.732	173.205

Table B4. Summary of parameters for roof 4.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
pH	6.73	7.00	6.82	6.83	0.09	0.013	1.337
Soil Water Content (Loosely Bound) (%)	19.884	28.551	25.101	24.916	3.327	0.134	13.353
Soil Organic Carbon Content (%)	2.698	4.928	4.384	4.152	0.802	0.193	19.308
Average Clay Content (%) (0.01 to 6.606934 µm)	6.360	14.282	9.355	9.779	2.789	0.285	28.520
Total Nitrogen (%)	0.29	0.58	0.44	0.44	0.11	0.238	23.772
Ammonium Nitrogen (NH_4^+) (ppm)	8.6	22.1	18.5	17.3	5.2	0.3	30.336
Nitrate Nitrogen (NO_3^-) (ppm)	2.9	12.4	4.5	5.8	3.5	0.609	60.893
Earthworm Count	0	3	0.5	1.0	1.3	1.265	126.491

Table B5. Summary of parameters for roof 5.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
pH	6.84	6.98	6.91	6.91	0.06	0.009	0.900
Soil Water Content (Loosely Bound) (%)	37.451	46.606	41.105	41.567	4.602	0.111	11.070
Soil Organic Carbon Content (%)	11.677	14.768	13.340	13.281	1.402	0.106	10.553
Average Clay Content (%) (0.01 to 6.606934 µm)	3.627	4.915	3.702	3.987	0.621	0.156	15.583
Total Nitrogen (%)	0.94	1.10	1.04	1.03	0.07	0.064	6.425
Ammonium Nitrogen (NH_4^+) (ppm)	35.9	56.2	42.8	44.4	8.9	0.200	20.011
Nitrate Nitrogen (NO_3^-) (ppm)	10.7	31.3	20.0	20.5	10.2	0.496	49.638
Earthworm Count	0	0	0	0	0	0	0

Table B6. Summary of parameters for roof 6.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
pH	6.71	6.93	6.87	6.85	0.08	0.011	1.133
Soil Water Content (Loosely Bound) (%)	46.463	62.876	61.069	58.085	6.530	0.112	11.241
Soil Organic Carbon Content (%)	10.115	12.761	10.748	11.087	1.049	0.095	9.458
Average Clay Content (%) (0.01 to 6.606934 µm)	2.139	3.657	2.224	2.596	0.653	0.251	25.147
Total Nitrogen (%)	0.85	1.13	1.03	1.02	0.10	0.099	9.882
Ammonium Nitrogen (NH_4^+) (ppm)	25.9	52.9	48.0	45.3	10.0	0.222	22.175
Nitrate Nitrogen (NO_3^-) (ppm)	5.7	39.5	15.4	19.2	14.0	0.729	72.875
Earthworm Count	0	37	7	10.833	13.906	1.284	128.360

Table B7. Summary of parameters for roof 7.

	Minimum	Maximum	Median	Mean	Standard Deviation	Coefficient of Variation	Relative Standard Deviation (%)
pH	6.68	6.97	6.81	6.82	0.10	0.015	1.513
Soil Water Content (Loosely Bound) (%)	64.369	70.792	67.345	67.533	2.798	0.041	4.144
Soil Organic Carbon Content (%)	9.162	11.475	9.947	10.362	1.055	0.102	10.178
Average Clay Content (%) (0.01 to 6.606934 µm)	1.175	1.353	1.221	1.244	0.072	0.058	5.802
Total Nitrogen (%)	0.90	1.24	1.12	1.10	0.13	0.116	11.642
Ammonium Nitrogen (NH_4^+) (ppm)	23.9	45.3	30.6	33.1	7.9	0.239	23.883
Nitrate Nitrogen (NO_3^-) (ppm)	5.4	10.2	8.9	8.1	2.2	0.271	27.135
Earthworm Count	0	12	3.0	4.4	5.128	1.166	116.553

Appendix C. Comparative Results Statistics

Table C.1a to Table C.2b show the results from the regression statistical analysis for the association between clay content and ammonium and nitrate content. Table C.3a to Table C.5b show the results from the multiple regression statistical analysis for variables associated with earthworm's presence, ammonium content, and nitrate content, after backward elimination was performed.

C.1. Clay Content and Ammonium Content

Table C.1a. Regression analysis of the influence of soil clay content on soil ammonium content.

Regression Statistics	
Multiple R	0.580
R Square	0.336
Adjusted R Square	0.315
Standard Error	11.531
Observations	34

Table C.1b. ANOVA analysis of the influence of soil clay content on soil ammonium content.

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F (p-value)*
Regression	1	2155.254	2155.254	16.210	3.254×10^{-4}
Residual	32	4254.661	132.958		
Total	33	6409.916			

C.2. Clay Content and Nitrate Content

Table C.2a. Regression analysis of the influence of soil clay content on soil nitrate content.

Regression Statistics	
Multiple R	0.227
R Square	0.051
Adjusted R Square	0.022
Standard Error	26.650
Observations	34

Table C.2b. ANOVA analysis of the influence of soil clay content on soil nitrate content.

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F (p-value)*
Regression	1	1232.944	1232.944	1.736	0.197
Residual	32	22727.105	710.222		
Total	33	23960.049			

C.3. Earthworm Presence and Explanatory Variables Multiple Variable Analysis

Table C.3a. Multiple regression analysis of earthworm presence and explanatory variables.

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2252.59371	750.86457	10.12	<.0001
Error	31	2299.40629	74.17440		
Uncorrected Total	34	4552.00000			

Table C.3b. Multiple analysis of earthworm presence and explanatory variables individual summary.

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
soil_depth	0.85574	0.34395	459.14574	6.19	0.0184
organicC	-1.05835	0.39330	537.11593	7.24	0.0114
trans_moisture	0.00023076	0.00005938	1120.26011	15.10	0.0005

C.4. Ammonium Content and Explanatory Variables Multiple Variable Analysis

Table C.4a. Multiple regression analysis of ammonium content and explanatory variables.

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	55548	18516	288.01	<.0001
Error	31	1992.94752	64.28863		
Uncorrected Total	34	57541			

Table C.4b. Multiple regression analysis of ammonium content and explanatory variables individual summary.

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
soil_depth	1.36242	0.25782	1795.27238	27.93	<.0001
Worms	0.29729	0.14627	265.59252	4.13	0.0507
moisture	0.48523	0.05235	5523.34571	85.91	<.0001

C.5. Nitrate Content and Explanatory Variables Multiple Variable Analysis

Table C.5a. Multiple regression analysis of nitrate content and explanatory variables.

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	27484	9161.40695	30.27	<.0001
Error	31	9380.93914	302.61094		
Uncorrected Total	34	36865			

Table C.5b. Multiple regression analysis of nitrate content and explanatory variables individual summary.

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
organicC	-3.34641	0.83309	4882.67016	16.14	0.0003
Total_N	104.94504	16.66764	11997	39.64	<.0001
moisture	-0.91736	0.28246	3191.89301	10.55	0.0028

Appendix D. Agricultural Green Roof Actors Survey Template

Interview questions

<u>Exploration of Agricultural Green Roofs Soils for Earthworm Populations, Nitrogen and the Possible Interactions and Practices Involved, Southern Ontario</u>: Agricultural Green Roof Actors

Answer the questions to the best of your ability. Please provide as many details as possible. If you are trying to determine whether or not information applies, provide the information in your answer anyways as it can be useful even if it only partially fits the criteria of the question. Do not hesitate to ask for clarification for any questions asked.

What is your name?

What is your phone number?

What is your e-mail address?

What is your education and/or experience background?

Which agricultural green roof are you involved with (relevant to this interview)?

How deep are the soil growing mediums that plants are grown in?

Why are these soil depths used?

What are the components of the soil mixture that plants are grown in, in other words what makes up the soil mixture?

What amendments have been made to the soil growing medium that plants are grown in, for and during the 2015 growing season? Describe details of the amendments made (locations of additions, amounts and compositions of added materials).

Describe the history of amendments that have been made to the soil growing medium that plants are grown in, over the past few years.

What plant varieties were grown during the 2015 growing season?

Describe the history of plants that have grown in the soil growing medium over the past few years.

How were the agricultural crops irrigated during the 2015 growing season?

On average, how frequently were the agricultural crops irrigated during the 2015 growing season?

Have earthworm's castings ever been added to the soil growing mediums? If so when, what years? Describe any details about the application such as location of application and amount and composition of the earthworm castings.

Has vermicompost ever been added to the soil growing mediums? If so when, what years? Describe any details about the application such as location of application, amount and composition of vermicompost applied.

Has vermicompost been produced on site (on the roof near the agricultural green roof application)? If so when, what years? Describe any details such as closeness to the agricultural plots.

Have earthworms ever been directly introduced into the soil growing mediums? If so when? Describe any details about the introduction such as types of earthworms, locations of introduction, amounts or earthworms introduced.

How is the soil growing medium managed (removal and replacement schedule, tilling, additional materials added on top of existing mixture)?

Describe any observations of the study areas which you find may be relevant or of interest.

References

Addison, J. (2009). Distribution and impacts of invasive earthworms in Canadian forest ecosystems. *Biological Invasions, 11(1),* 59-79. doi: 10.1007/s10530-008-9320-4

Aitkenhead-Peterson, J. A., Dvorak, B. D., Volder, A., and Stanley, N. C. (2011). Chemistry of growth medium and leachate from green roof systems in south-central Texas. *Urban Ecosystems, 14(1),* 17-33. doi: 10.1007/s11252-010-0137-4

Allen, V. T., and Johns, W. D. (1960). Clays and clay minerals of New England and Eastern Canada. *Geological Society of America Bulletin, 71(1),* 75-86. doi: https://doi.org/10.1130/0016-7606(1960)71[75:CACMON]2.0.CO;2

Angers, D. A., Bolinder, M. A., Carter, M. R., Gregorich, E. G., Drury, C. F., Liang, B. C., Voroney, R. P., Simard, R. R., Donald, R. G., Beyaert, R. P., and Martel, J. (1997). Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. *Soil & Tillage Research, 41(3-4),* 191-201.

Arriaga, F. J., Lowery, B., and Mays, M. D. (2006). A fast method for determining soil particle size distribution using a laser instrument. *Soil Science, 171(9),* 663-674.

Asady, G. H., and Smucker, A. J. M. Compaction and root modifications of soil aeration. *Soil Science Society of America Journal, 53(1),* 251-254.

Auerswald, K., Weigand, S., Kainz, M., and Philipp, C. (1996). Influence of soil properties on the population of geophagous earthworms after five years of bare fallow. *Biology and Fertility of Soils, 23(4),* 382-387.

Balaine, N., Clough, T. J., Beare, M. H., Thomas, S. M., Meenken, E. D., and Ross, J. G. (2013). Changes in relative gas diffusivity explain soil nitrous oxide flux dynamis. *Soil Science Society of America Journal, 77(5),* 1496-1505. doi:10.2136/sssaj2013.04.0141

Beare, M. H., Gregorich, E. G., and St-Georges, P. (2009). Compaction effects on CO_2 and N_2O production during drying and rewetting of soil. *Soil Biology and Biochemistry, 41(3),* 611-621. doi:10.1016/j.soilbio.2008.12.024

Blanchart, E., Albrecht, A., Brown, G., Decaens, T., Duboisset, A., Lavelle, P., Mariani, L., and Roose, E. (2004). Effects of tropical endogeic earthworms on soil erosion. *Agriculture, Ecosystems & Environment, 104(2),* 303-315. doi: 10.1016/j.agee.2004.01.031

Blay-Palmer, A. (2009). The Canadian pioneer: The genesis of urban food policy in Toronto. *International Planning Studies, 14(4),* 401-416.

Berndtsson, J. C., Bengtsson, L., and Jinno, K. (2009). Runoff water quality from intensive and extensive vegetated roofs. *Ecological Engineering, 35(3),* 369-380.

Berndtsson, J. C., Emilsson, T., and Bengtsson, L. (2006). The influence of extensive vegetated roofs on runoff water quality. *Science of the Total Environment, 355(1),* 48-63.

Bolan, N. S., and Kandaswamy, K. (2005). pH. In *Encyclopedia of Soils in the Environment*. Retrieved from http://1.droppdf.com/files/3eUvv/encyclopedia-of-soils-in-the-environment-volume-3.pdf

Brenneisen, S. (2006). Space for urban wildlife: Designing green roofs as habitats in Switzerland. *Urban Habitats, 4(1),* 27-36.

Buffam, I., and Mitchell, M. E. (2015). Nutrient cycling in green roof ecosystems. In R. Sutton (Ed.), *Green Roof Ecosystems* (pp. 107-137). Switzerland: Springer International Publishing.

Canadian Agricultural Services Coordinating Committee & Soil Classification Working Group. (1998). *The Canadian System of Soil Classification*. NRC Research Press.

Carter, M. R., Angers, D. A., Gregorich, E. G., and Bolinder, M. A. (1997). Organic carbon and nitrogen stocks and storage profiles in cool, humid soils of eastern Canada. *Canadian Journal of Soil Science, 77(2),* 205-210.

Chaoui, H. I., Zibilske, L. M., and Ohno, T. (2003). Effects of earthworms casts and compost on soil microbial activity and plant nutrient availability. *Soil Biology and Biochemistry, 35(2),* 295-302. doi: 10.1016/S0038-0717(02)00279-1

City of Toronto, By-law No. 583-2009, *To adopt City of Toronto Municipal Code Chapter 492, Green Roofs, under s. 108 of the City of Toronto Act, 2006* (27 May, 2009).

City of Toronto. (2013). *Staff report for action on the Toronto Agricultural Program*. Retrieved from https://www.toronto.ca/legdocs/mmis/2013/pe/bgrd/backgroundfile-62375.pdf

Coja, T., Zehetner, K., Bruckner, A., Watzinger, A., and Meyer, E. (2008). Efficacy and side effects of five sampling methods for soil earthworms (Annelida, Lumbricidae). *Ecotoxicology and Environmental Safety, 71(2),* 552-565. doi: 10.1016/j.ecoenv.2007.08.002

Costello, D. M. (2010). *Effects of invasive species and chemical contaminants on biogeochemical fluxes across ecosystem boundaries*. Available from ProQuest Dissertations & Theses A&I; ProQuest Dissertations & Theses Global. (288140737).

Costello, D. M., and Lamberti, G. A. (2008). Non-native earthworms in riparian soils increase nitrogen flux into adjacent aquatic ecosystems. *Oecologia, 158(3),* 499-510. doi: 10.1007/s00442-008-1149-0

Costello, D. M., and Lamberti, G. A. (2009). Biological and physical effects of non-native earthworms on nitrogen cycling in riparian soils. *Soil Biology and Biochemistry, 41(10),* 2230-2235. doi: 10.1016/j.soilbio.2009.08.007

Costello, D. M., Tiegs, S. D., and Lamberti, G. A. (2011). Do non-native earthworms in Southeast Alaska use streams as invasional corridors in watersheds harvested for timber? *Biological Invasions, 13(1),* 177-187. doi: 10.1007/s10530-010-9800-1

Curtin, D., Beare, M. H., and Hernandez-Ramirez, G. (2012). Temperature and moisture effects on microbial biomass and soil organic matter mineralization. *Soil Science of America Journal, 76(6),* 2055-2067. doi:10.2136/sssaj2012.0011

Di Stefano, C., Ferro, V., and Mirabile, S. (2010). Comparison between grain-size analyses using laser diffraction and sedimentation methods. *Biosystems Engineering, 106(2),* 205-215.

Dobbie, K. E., McTaggart, I. P., and Smith, K. A. (1999). Nitrous oxide emissions from intensive agricultural systems: Variations between crops and seasons, key driving variables, and mean emission factors. *Journal of Geophysical Research, 104(D21),* 26891-26899.

Dobbie, K. E., and Smith, K. A. (2001). The effects of temperature, water-filled pore space and land use on N_2O emissions from an imperfectly drained gleysol. *European Journal of Soil Science, 52(4),* 667-673.

Drew, M. C. (1990). Sensing soil oxygen. *Plant, Cell & Environment, 13(7),* 681-693.

Drury, C. F., Zhang, T. Q., and Kay, B. D. (2003). The non-limiting and least limiting water ranges for soil nitrogen mineralization. *Soil Science of America Journal, 67(5),* 1388-1404.

Dunnett, N., and Nolan, A. (2002). The effect of substrate depth and supplementary watering on the growth of nine herbaceous perennials in a semi-extensive green roof. In *International Conference on Urban Horticulture, 643* (pp. 305-309).

Edwards, W. M., Shipitalo, M. J., Owens, L. B., and Norton, L. D. (1989). Water and nitrate movement in earthworm burrows within long-term no-till cornfields. *Journal of Soil and Water Conservation, 44(3),* 240-243.

Edwards, W. M., Shipitalo, M. J., Owens, L. B., and Norton, L. D. (1990). Effect of *Lumbricus terrestris* L. burrows on hydrology of continuous no-till corn fields. *Geoderma, 46(1-3),* 73-84.

Eijsackers, H. (2011). Earthworms as colonizers of natural and cultivated soil environments. *Applied Soil Ecology, 50,* 1-13.

Eshel, G., Levy, G. J., Mingelgrin, U., and Singer, M. J. (2004). Critical evaluation of the use of laser diffraction for particle-size distribution analysis. *Soil Science of America Journal, 68,* 736-743.

Evers, A. K., Gordon, A. M., Gray, P. A., and Dunlop, W. I. (2012). *Implications of a potential range expansion of invasive earthworms in Ontario's forested ecosystems: a preliminary vulnerability analysis* (No. CCRR-23). Sault Ste. Marie, ON: Applied Research and Development Branch, Ministry of Natural Resources, 2012.

Galloway, J. N., Aber, J. D., Erisman, J. W., Seitzinger, S. P., Howarth, R. W., Cowling, E. B., and Cosby, B. J. (2003). The nitrogen cascade. *BioScience, 53(4),* 341-356.

Galloway, J. N., Schlesinger, W. H., Levy, H., Michaels, A., and Schnoor, J. L. (1995). Nitrogen fixation: Anthropogenic enhancement-environmental response. *Global Biogeochemical Cycles, 9(2),* 235-252.

Getter, K. L., and Rowe, D. B. (2006). The role of extensive green roofs in sustainable development. *HortScience, 41(5),* 1276-1285.

Hale, C.M. (2013). Earthworms of the Great Lakes. Kollath and Stensaas, Duluth, MN.

Hale, C. M., Frelich, L. E., and Reich, P. B. (2005). Exotic European earthworm invasion dynamics in northern hardwood forests of Minnesota, USA. *Ecological Applications, 15(3),* 848-860.

Hale, C. M., Reich, P. B., and Frelich, L. E. (2004). Allometric equations for estimation of ash-free dry mass from length measurements for selected European earthworm species (Lumbricidae) in the Western great lakes region. *The American Midland Naturalist, 151(1),* 179-185. doi: 10.1674/0003-0031(2004)151[0179:AEFEOA]2.0.CO;2

Harrison, R. B., Footen, P. W., and Strahm, B. D. (2011). Deep soil horizons: Contribution and importance to soil organic carbon pools and in assessing whole-ecosystem response to management and global change. *Forest Science, 57(1),* 67-76.

Hathaway, A. M., Hunt, W. F., and Jennings, G. D. (2008). A field study of green roof hydrologic and water quality performance. *Transaction of the American Society of Agricultural and Biological Engineers, 51(1),* 37-44.

Heiri, O., Lotter, A. F., and Lemcke, G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: Reproducibility and comparability of results. *Journal of Paleolimnology, 25(1),* 101-110. doi: 10.1023/A:1008119611481

Hill, A. R. (2011). Buried organic-rich horizons: Their role as nitrogen sources in stream riparian zones. *Biogeochemistry, 104(1-3),* 347-363.

Holmstrup, M. (2003). Overwintering adaptations in earthworms: The 7th international symposium on earthworm ecology· Cardiff· Wales· 2002. *Pedobiologia – International Journal of Soil Biology, 47(5-6),* 504-510.

Hoogsteen, M. J. J., Lantinga, E. A., Baker, E. J., Groot, J. C. J., and Tittonell, P. A. (2015). Estimating soil organic carbon through loss on ignition: Effects of ignition conditions and structural water loss. *European Journal of Soil Science, 66(2),* 320-328. doi: 10.1111/ejss.12224

Hoorman, J., Aziz, I., Reeder, R., Sundermeier, A., and Islam, R. (2011). Soil terminology and definitions. *Agricultural and Natural Resources Fact Sheet*. *SAG-19-11*, 1-8.

House, G. J., and Parmelee, R. W. (1985). Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. *Soil & Tillage Research, 5(4)*, 351-360.

Howard, P. J. A., and Howard, D. M. (1990). Use of organic carbon and loss-on-ignition to estimate soil organic matter in different soil types and horizons. *Biology and Fertility of Soils, 9(4)*, 306-310.

Huang, P., Patel, M., Santagata, M. C., and Bobet, A. 2009. Classification of Organic Soils. Publication FHWA/IN/JTRP-2008/02. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2009. doi: 10.5703/1288284314328

Joschko, M., Diestel, H., and Larink, O. (1989). Assessment of earthworm burrowing efficiency in compacted soil with a combination of morphological and soil physical measurements. *Biology and Fertility of Soils, 8(3)*, 191-196.

Kaethler, T. M. (2006). *Growing space: The potential for urban agriculture in the city of Vancouver*. School of Community and Regional Planning University of British Columbia.

Kaplan, D. L., Hartenstein, R., Neuhauser. E. F., and Maleck, M. R. (1980). Physicochemical requirments in the environment of the earthworm *Eisenia foetida*. *Soil Biology and Biochemistry, 12(4)*, 347-352.

Kalra, Y. P. (1995). Determination of pH of soils by different methods: Collaborative study. *Journal of AOAC International, 78(2)*, 310-324.

Kalra, Y. P., and Maynard, D. G. (1991). *Methods manual for forest soil and plant analysis.* Forestry Canada, Northwest Region, Northern Forestry Centre, Information Report NOR-X-319.

Kawaguchi, T., Kyoshima, T., and Kaneko, N. (2011). Mineral nitrogen dynamics in the casts of epigeic earthworms (*Metaphire* hilgendorfi: Megascolecidae). *Soil Science and Plant Nutrition, 57(3)*, 387-395. doi: 10.1080/00380768.2011.579879

Keele, J. (1942). *Preliminary report on the clay and shale deposits of Ontario.* Department of Mines, Canada.

Keller, J. M., and Gee, G. W. (2006). Comparison of American Society of Testing Materials and Soil Science Society of America hydrometer methods for particle-size analysis. *Soil Science Society of America Journal, 70(4),* 1094-1100.

Kladivko, E. J. (2001). Tillage systems and soil ecology. *Soil and Tillage Research, 61(1),* 61-76. doi: 10.1016/S0167-1987(01)00179-9

Kodoma, H. (1979). Clay minerals in Canadian soils: Their origin, distribution and alteration. *Canadian Journal of Soil Science, 59(1),* 37-58.

Kothawala, D. N., and Moore, T. R. (2009). Adsorption of dissolved nitrogen by forest mineral soils. *Canadian Journal of Forest Research, 39(12),* 2381-2390. doi: 10.1139/X09-147

Ksiazek, K., Fant, J., and Skogen, K. (2012). An assessment of pollen limitation on Chicago green roofs. *Landscape and Urban Planning, 107,* 401-408.

Lunt, H. A. (1931). The carbon-organic matter factor in forest soil humus. *Soil Science, 32(1),* 27-34.

MacIvor, J. S., and Lundholm, J. (2011). Insect species composition and diversity on intensive green roofs and adjacent level-ground habitats. *Urban Ecosystems, 14(2)*, 225-241. doi: 10.1007/s11252-010-0149-0

Madre, F., Vergnes, A., Machon, N., and Clergeau, P. (2013). A comparison of 3 types of green roof as habitats for arthropods. *Ecological Engineering, 57*, 109-117.

Malcolm, E. G., Reese, M. L., Schaus, M. H., Ozmon, I. M., and Tran, L. M. (2014). Measurements of nutrients and mercury in green roof and gravel roof runoff. *Ecological Engineering, 73*, 705-712.

Meshcheryakova, E. N., and Berman, D. I. (2014). Cold hardiness and geographic distribution of earthworms (Oligochaeta, Lumbricidae, Moniligastridae). *Entomological Review, 94(4)*, 486-497. doi: 10.1134/S0013873814040046

Mikkelson, K., and Vesho, I. (2000). *Riparian soils: A literature review*. University of Washington Water Center. Retrieved from https://dlib.lib.washington.edu/researchworks/bitstream/handle/1773/17038/Riparian%20Soils%20Literature%20Review.pdf?sequence=1

Miller, B. A., and Schaetzl, R. J. (2012). Precision of soil particle size analysis using laser diffractometry. *Soil Science Society of America Journal, 76,* 1719-1727.

Morin, J. (1993). Soil crusting and sealing. *In Soil tillage in Africa: Needs and challenges* (Chapter 5). Retrieved from http://www.fao.org/docrep/t1696e/t1696e06.htm#P16_122

Muys, B., and Granval, P. H. (1997). Earthworms as bio-indicators of forest site quality. *Soil Biology and Biochemistry, 29(3-4),* 323-328.

Neuhauser, E. F., Kaplan, D. L., Malecki, M. R., and Hartenstein, R. (1980). Materials supporting weight gain by the earthworm *Eisenia foetida* in waste conversion systems. *Agricultural Wastes, 2(1),* 43-60.

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., Gaffin, S., Kohler, M., Liu, K. K. Y., and Rowe, B. (2007). Green roofs as urban ecosystems: Ecological structures, functions, and services. *BioScience, 57(10),* 823-833.

Pansu, M., and Gautheyrou, J. (2006). *Handbook of soil analysis: Mineralogical, organic and inorganic methods*. New York: Springer Berlin Heidelberg.

Paoletti, M. G. (1999). The role of earthworms for assessment of sustainability and as bioindicators. *Agriculture, Ecosystems and Environment, 74(1),* 137-155. doi: 10.1016/S0167-8809(99)00034-1

Parkin, T. B., and Berry, E. C. (1999). Microbial nitrogen transformations in earthworm burrows. *Soil Biology and Biochemistry, 31(13),* 1765-1771.

Paul, K. I., Polglase, P. J., O'Connell, A. M., Carlyle, J. C., Smethurst, P. J., and Khanna, P. K. (2003). Defining the relation between soil water content and net nitrogen mineralization. *European Journal of Soil Science, 54(1),* 39-47.

Peck, S. W., & Kuhn, M. (2003). *Design guidelines for green roofs*. Toronto: Ontario Association of Architects.

Pinder, R. A. (2013). *Ecology of earthworms in riparian habitats*. Available from ProQuest Dissertations & Theses A&I; ProQuest Dissertations & Theses Global. (1419999664).

Pribyl, D. W. (2010). A critical review of the conventional SOC to SOM conversion factor. *Geoderma, 156(3),* 75-83. doi:10.1016/j.geoderma.2010.02.003

Reinecke, A. J., and Venter, J. M. (1987). Moisture preferences, growth and reproduction of the compost worm *Eisenia fetida* (Oligochaeta). *Biology and Fertility of Soils, 3(1),* 135-141.

Römbke, J., Jänsch, S., and Didden, W. (2005). The use of earthworms in ecological soil classification and assessment concepts. *Ecotoxicology and Environmental Safety, 62(2),* 249-265.

Rowe, D. B., Monterusso, M. A., and Rugh, C. L. (2006). Assessment of heat-expanded slate and fertility requirements in green roof substrates. *HortTechnology, 16(3),* 471-477.

Scheu, S. (2003). Effects of earthworms on plant growth: Patterns and perspectives. *Pedobiologia, 47(5),* 846-856. doi: 10.1016/S0031-4056(04)70279-6

Scheu, S., and Parkinson, D. (1994). Effects of earthworms on nutrient dynamics, carbon turnover and microorganisms in soils from cool temperature forests of the Canadian Rocky Mountains – laboratory studies. *Applied Soil Ecology, 1*(2), 113-125. doi: 10.1016/0929-1393(94)90031-0

Scheu, S, Theenhaus, A, and Jones, T. H. (1999). Links between the detritivore and the herbivore system: effects of earthworms and Collembola on plant growth and aphid development. *Oecologia, 119(4),* 541-551. doi: 10.1007/s004420050817

Schrader, S., and Boning, M. (2006). Soil formation on green roofs and its contribution to urban biodiversity with emphasis on Collembolans. *Pedobiologia, 50(4)*, 347-356. doi: 10.1016/j.pedobi.2006.06.003

Schwert, D. P. (1990). Oligochaeta: Lumbricidae. In: D. L. Dindal (Ed.), *Soil Biology Guide*, pp. 341-356. New York: John Wiley & Sons.

Shipitalo, M. J., Nuutinen, V., and Butt, K. R. (2004). Interaction of earthworm burrows and cracks in a clayey subsurface-drained, soil. *Applied Soil Ecology, 26*, 209-217. doi:10.1016/j.apsoil.2004.01.004

Siddique, J., Khan, A. A., Hussain, I., and Akhter, S. (2005). Growth and reproduction of earthworm (*Eisenia fetida*) in different organic media. *Pakistan Journal of Zoology, 37(3)*, 211-214.

Smith, M. S., and Tiedje, J. M. (1979). Phases of denitrification following oxygen depletion in soil. *Soil Biology and Biochemistry, 11(3)*, 261-267.

Suthar, S. (2008). Microbial and decomposition efficiencies of monoculture and polyculture vermireactors, based on epigeic and anecic earthworms. *World Journal of Microbiology and Biotechnology, 24(8)*, 1471-1479. doi: 10.1007/s11274-007-9635-9

Syers, J. K., and Springett, J. A. (1984). Earthworms and soil fertility. *Plant and Soil, 76(1-3)*, 93- 104. doi: 10.1007/BF02205570

Taylor, D. (1948). *Fundamentals of soil mechanics*. New York: John Wiley & Sons.

Tonietto, R., Fant, J., Ascher, J., Ellis, K., and Larkin, D. (2011). A comparison of bee communities of Chicago green roofs, parks and prairies. *Landscape and Urban Planning, 103*, 102-108.

Toronto Food Policy Council. (2012). GrowTO: An urban agriculture action plan for Toronto. Retrieved from https://www.toronto.ca/legdocs/mmis/2012/pe/bgrd/backgroundfile-51558.pdf

Toronto Food Policy Council. (n.d.). *Urban Agriculture*. Retrieved from http://tfpc.to/to-food-policy-archive/urban-agriculture

Toronto Urban Growers. (2017, November 30). *Organizations*. Retrieved from http://torontourbangrowers.org/organizations

Trigo, D., Mato, S., Souto, B. F., and Diaz Cosin, D. J. (1989). Earthworms of continental Portugal. Relationships with soil factors. *Italian Journal of Zoology, 56(4)*, 327-331.

Tripathi, G., and Bhardwaj, P. (2004). Comparative results on biomass production, life cycles and composting efficiency of *Eisenia fetida* (Savigny) and *Lampito mauritii* (Kinberg). *Bioresource Technology, 92*, 275-283. doi:10.1016/j.biortech.2003.09.005

Turtola, E., and Paajanen, A. (1995). Influence of improved subsurface drainage on phosphorous losses and nitrogen leaching from heavy clay soils. *Agricultural Water Management, 28(4)*, 295-310. doi: 10.1016/0378-3774(95)01180-3

Van Lierop, W. M., and MacKenzie, A. F. (1977). Soil pH measurement and its application to organic soils. *Canadian Journal of Soil Science, 57(1)*, 55-64.

Van Seters, T., Rocha, L., Smith, D., and MacMillan, G. (2009). Evaluation of green roofs for runoff retention, runoff quality, and leachability. *Water Quality Research Journal of Canada, 44(1),* 33-47.

Van Veenhuizen, R., and Danso, G. (2007). *Profitability and sustainability of urban and periurban agriculture* (Vol. 9). Food and Agriculture Organization.

Wang, Q., Li, Y., Wang, Y. (2011a). Optimizing the weight loss-on-ignition methodology to quantify organic and carbonate carbon of sediments from diverse sources. *Environmental Monitoring and Assessment, 174(1),* 241-257. doi: 10.1007/s10661-010-1454-z

Wang, Y., Lu, S., Ren, T., and Li, B. (2011b). Bound water content of air-dry soils measured by thermal analysis. *Soil Science Society of America Journal, 75(2),* 481-487. doi: 10.2136/sssaj2010.0065.

Whittinghill, L. J., and Rowe, D. B. (2012). The role of green roof technology in urban agriculture. *Renewable Agriculture and Food Systems, 27(4),* 314-322. doi:10.1017/S174217051100038X

Whittinghill, L. J., Rowe, D. B., Andresen, J. A., and Cregg, B. M. (2015). Comparison of stormwater runoff from sedum, native prairie, and vegetable producing green roofs. *Urban Ecosystems, 18(1),* 13-29. doi: 10.1007/s11252-014-0386-8

Whittinghill, L. J., Rowe, D. B., and Cregg, B. M. (2013). Evaluation of vegetable production on extensive green roof. *Agroecology and Sustainable Food Systems, 37(4),* 465-484. doi: 10.1080/21683565.2012.756847

Zejun, T., Tingwu, L., Qingwen, Z., and Jun, Z. (2002). The sealing process and crust formation at soil surface under the impacts of raindrops and polyacrylamide. *Proceedings of the 12th Conference of the ISCO*, 456-462.

Zobeck, T. M. (2004). Rapid soil particle size analyses using laser diffraction. *Applied Engineering in Agriculture, 20(5),* 633-639.