Nitrous Oxide Soil Emissions from an Organic and Conventionally Managed Cropping System in Manitoba

By

Megan Westphal

A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

In partial fulfilment of the requirements of the degree of

Master of Science

Department of Soil Science

University of Manitoba

Winnipeg

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Abstract:

In recent decades the knowledge of nitrous oxide (N_2O) emissions after the application of nitrogen (N) fertilizers in agriculture soil has improved. However the understanding of emissions of N_2O from Canadian organic agricultural systems has not been developed. The Glenlea Long Term Crop Rotation is the longest running organic conventional comparison study in western Canada and was used here to compare N_2O emissions between the systems. In organic cropping systems forage legumes such as alfalfa are incorporated into the soil as an N source. The amount of N_2O that is emitted after the incorporation and during the subsequent crop is not well known. The wheat and legume phases (alfalfa (*Medicago sativa*) in organic system and soybean (*Glycine max* L.) in the conventional) of the rotation were monitored for N_2O. In 2014, 2015, and spring 2016 (data still being analysed) emissions of N_2O were monitored using the vented static chambers method as well, soil conditions (temperature, moisture, inorganic N and extractable carbon) and yields were measured. Typical N_2O emissions from spring applied urea were observed after application in the conventional system however no emission episode was seen after the fall alfalfa plough down or during spring thaw in the organic system. Greater NO_3^- accumulation was observed in the organic treatments however low emissions were observed. The organic system resulted in lower yields for both years, but still resulted in lower emissions per amount of grain produced (yield-scaled emissions) than the conventional system. This study adds to the knowledge that N_2O emissions from organic systems do differ from conventional however yields need to be improve to fully exploit the benefits.

Acknowledgements:

This thesis would not have been possible without the support, dedication, and encouragement from all the people involved for this research project. I am extremely thankful for such amazing and enthusiastic supervising professor and committee members Dr. Mario Tenuta, Dr. Martin Entz, and Dr. Brian Amiro respectively. They have led me to challenge myself scientifically while still maintaining a fun and relaxed atmosphere. None of these results would have been possible without the help from some remarkable technicians Brad Sparling, Keith Bamford, Mervin Bilous, Rob Ellis, and Joanne Theissen-Martens. In addition I would also like to thank the number of summer students (a.k.a The Soil Mates) who have assisted me in the field Geneva Cloutis, Greg Wiebe, Ian Copps, Natasha Klassen, Taliah Klippenstein-Epp, and Ulana Fries. I am forever indebted and wish them all the best in their future endeavours. On the other side of research there is much need to thank the support staff Lynda Closson, Martha Blouw, Jennifer Henderson, and Terry Ramm who have made everything to do with paper a breeze. My partner in life Krisjan Morrow I could not have done this without your continued support and supportive nature. Finally I would like to thank the soil microbiota and their flatulent nature allowing me to conduct this research and expand my scientific knowledge.

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1.1 Introduction

The Glenlea Long-Term Crop Rotation and Management site (GLTCR) was established in 1992 on the west side of HWY 75on the University of Manitoba's Glenlea Research Station (49.39 N and 97.7 W). The site is now in its 25th year of rotation and is the longest running organic-conventional management system comparison in western Canada. The experimental design of this study site is a randomized complete block design with three replicates along with restored prairie grasslands in each replicate. These serve as a standard for soil and environmental measurements (Braman 2012). The current crop rotation consists of a grain only rotation and a grain-forage rotation under both conventional and organic management. This site serves as an excellent resource for undergraduate and graduate student training and answering many research questions on the difference between conventional and organic management systems (Natural Systems Agriculture 2012).

In the 25 years the rotation has been running, many studies have been conducted. Research topics included crop yield, quality, and soil nutrient status between conventionally and organically grown wheat (Turmel et al. 2009), plant available phosphorus (P) in organic systems (Welsh et al. 2009), soil carbon (C) and nutrient stocks (N and P) (Bell et al. 2012). Mycorrhizal colonization on flax has also been studied at GLTCR (Entz et al. 2004; Kirk et al. 2011). Studies comparing differences in the soil food web between organic and conventional systems for example; bacterial communities and activity (Li et al. 2012; Braman 2012) and nematodes (Briar et al. 2012). Energy use and efficiency have also been compared between the two management systems comparing how much energy is used for inputs and produced (Entz et al. 2004; Entz et al. 2005; Hoeppner et al. 2005).Weeds, disease, and economics between the two systems have also been studied at the GLTCR (Entz et al. 2014). These publications provide valuable information and insight on how conventional and organic agricultural practices differ.

Greenhouse gas emissions (GHG) from agriculture have been a rising concern over the past decades with much attention given to reducing soil nitrous oxide (N_2O) emissions. Environment Canada provides an annual GHG inventory determined from methods and models developed from in-house engineer staff as well as from the scientific community (Environment Canada 2016). A country and region specific Tier II emission factor to calculate annual N_2O emissions from soil is used to determine annual N_2O emissions from agricultural soils in Canada. A search of peer-reviewed articles revealed studies comparing N_2O emissions between organic and conventional systems is lacking for Canada. With the rise in organic agriculture area in Canada, accurate estimation of N_2O emissions from these systems to develop GHG inventories is important.

Organic systems have different sources of N and the current emission factors largely based on N inputs from synthetic fertilizers and livestock manures used may not be suitable. A study conducted at the GLTCR looking at GHG between the two systems would be a great asset of information. Not only to support calculations and development of annual N_2O emissions, but also to the GLTCR to aid in fully understanding the dynamics and differences between organic and conventional systems.

1.2 Nitrous oxide; a greenhouse gas

Greenhouse gas emissions both natural and anthropogenic are becoming an increasing problem to the Earth's atmosphere. The three major GHG are carbon dioxide (CO_2) methane (CH_4), and N_2O. These gases are trapped within the Earth's atmosphere and contribute to ozone depletion and increased absorption of infrared radiation leading to global warming and climate change. This increase in atmospheric GHG can be largely attributed to anthropogenic fossil fuel burning, land use and land use change, and natural processes (IPCC 2013). According to the Intergovernmental Panel on Climate Change (IPCC), CO_2 has increased from 278 ppm in 1750 (pre-industrial era) to 390.5 ppm (increase of 40%) in 2011, CH_4^+ has increased from 722 ppb to 1803 ppb (150% increase), and N_2O increased from 271 ppb to 324.2 ppb (20% increase). The current study will focus on N_2O emissions. Though N_2O has the lowest concentration in the atmosphere among the major GHG it has the most damaging effect on the atmosphere having 265x the global warming potential of CO_2 on a 100 year time scale (IPCC 2013). Along with N_2O having a strong GHG effect it also has a long atmospheric lifetime consisting of 118 – 131 years (Ciais et al. 2013). This means that after the stabilization of global emissions it will take over 100 years for the atmosphere to become stable (Ciais et al. 2013). In Canada agriculture is responsible for 70% of anthropogenic N_2O emissions with the majority coming from soils after N fertilizer application (Environment Canada 2016).

Greenhouse gas inventories are conducted annually in Canada by the Pollutant Inventories and Reporting Division of Environment Canada. Canada's GHG inventory is organized in accordance with the United Nations Framework Convention on Climate Change (UNFCC). Estimates are determined by methods and models developed by scientific and engineering staff as well as from peer-reviewed published data or data developed from the IPCC (Environment Canada 2016). Canada now uses a country and region specific Tier II N_2O emission factor. For the Prairie black soil region where Glenlea, Manitoba is located the Tier II emission factor of 0.8% of added synthetic fertilizer N emitted as N_2O to the atmosphere (Rochette et al. 2008).

1.3 Soil Nitrous Oxide Production:

Nitrous oxide is emitted by many sources; from microbial processes within the soil, fossil fuel combustion, industrial processes, biomass burning, atmospheric deposition, and human sewage (IPCC 2007). Soil has been attributed as the largest source of N_2O which is mainly attributed to human agriculture from the application of N fertilizers to the soil. The IPCC has formulated that approximately 67% of human induced N_2O emissions is due to the early application of N fertilizer (IPCC 2006). As mentioned earlier in Canada 70% of N_2O emissions is from agricultural soil (Environment Canada 2016). This can be attributed to the application of N to the soil before the crop can utilize it and leaves it vulnerable in the soil to other N using processes.

Soil N_2O gas emission is the product of naturally occurring processes such as nitrification, nitrifier-denitrification, and denitrification caused by microbial activity (Norton 2008; Coyne 2008). The first process nitrification is carried out by ammonia and nitrite-oxidizing bacteria or also known as nitrifying bacteria. During nitrification, ammonium (NH_4^+) is oxidized to nitrite (NO_2^-) and further to nitrate (NO_3^-). Nitrous oxide is released as an intermediate product in this process when hydroxylamine (NH_2OH) (an intermediate product of the oxidation of NH_4^+ to NO_2^-) is oxidized to NO_2^- and then reduced to N_2O known as chemodenitrification (Chalk and Smith 1983; Wrage et al. 2001; IPCC 2006). Nitrifying bacteria under low oxygen (O_2) environments can also perform denitrification known as nitrifier-denitrification and release N_2O (Kool et al. 2011), where NO_2^- is used as an electron acceptor instead of O_2 and is reduced to N_2O or N_2 (Wrage et al. 2001; Kool et al. 2011).

Another source of soil N_2O is when NO_3^- is reduced in low O_2 conditions through a process called denitrification. Denitrification is the conversion of NO_3^- back to dinitrogen gas (N_2) carried out by denitrifying bacteria (Coyne 2008). Nitrate is used as terminal electron acceptor in place of O_2 and is transformed back to NO_2^- by the enzyme nitrate reductase, then further to nitric oxide gas (NO) via the nitrite reductase enzyme, then to N_2O by the NO reductase enzyme and then to N_2 by the N_2O reductase enzyme (Wrage et al. 2001; IPCC 2006). The process will be fully completed only if anaerobic environmental conditions are met; otherwise NO or N_2O will be released instead of N_2 (Wrage et al. 2001; Coyne 2008).

Nitrous oxide is also emitted from many indirect processes as well; following the volatilization of NH_3 and NO_x gases (N_2O, NO, NO_2) from managed soils and fossil fuel combustion with their products (NH_4^+ and NO_3^-) re-deposited from the air or atmosphere to soil and water surfaces which can then be nitrified or denitrified. Leached N to surface or ground water off the farm can also be nitrified or denitrified and released as N_2O (IPCC 2006). The amount of N_2O released from the process mentioned above is controlled by many factors such as substrate availability, soil moisture content and O_2 content, temperature, soil organic carbon, and soil texture.

1.3.1 Factors controlling N_2O release

Nitrous oxide emission rates from the soil are influenced by many soil factors. There are primary factors that directly control the release of N_2O such as substrate availability and soil C (Beauchamp 1997). Soil management practices can also affect the release of N_2O from the soil by indirectly affecting the C content, water holding capacity or infiltration rates.

Substrate availability is the concentration of inorganic N (NH_4^+ and NO_3^-) within the soil. The greater the amount of inorganic N the greater the amount of N_2O released (Tabatabai et al. 1992; Bremner 1997; Wrage et al. 2004). Inorganic N sources are provided in agricultural systems by the addition of N fertilizer, animal manures, legume forages, or green manures. The release of N from these different sources is also controlled by many soil factors and can affect the amount of N_2O emitted.

The amount of moisture within the soil as well as O_2 availability can also affect the amount of N_2O that can be released from the soil. Nitrification is an aerobic process meaning dry soils or soils in the process of drying after a rain event can lead to greater nitrification rates potentially leading to greater N_2O release (Sahrawat 2008; Norton and Stark 2011). Denitrification and nitrifier-denitrification are anaerobic and semi-anaerobic processes, respectively and greater soil moisture content with low O_2 content can lead to greater N_2O emissions (Wrage et al. 2001; IPCC 2006).

Soil temperature is an important factor that affects the release of N_2O from the soil. Goodroad and Keeney (1983) reported that temperature was a controlling factor for N_2O release with greater microbial activity as temperature increased. It has been reported that optimal temperature for N_2O processes was found to be climate dependent (Sahrawat 2008; Clark et al. 2009). This means that soils from different climatic areas will have different rates of N_2O release at varying temperatures because of the adaptations of the microorganisms.

Soil carbon content is another major factor that controls N_2O release. Incubation studies and field studies have found that soils with greater soil organic carbon (SOC) content tended to have greater soil N_2O emissions (Goodroad and Keeney 1984; Tenuta and Sparling 2011; Li et al. 2005). Denitrifiers synthesize organic C as an energy source and increases in soil organic C coupled with a high soil NO_3^- concentration could lead to increased emissions (Li et al. 2005). Soil C can also affect soil properties such as cation exchange capacity, water holding capacity and bulk density of the soil which can in turn affect the amount of substrate availability and the environment of the N_2O producing organisms (Li et al. 2005).

Soil texture (the amount of sand, silt, and clay within the soil) also plays a role in the amount of N_2O released. Soil texture can affect many aspects of the soil such as water holding capacity, marco- and micro-porosity, and bulk density (Pihlatie et al. 2004; Sahrawat 2008). The differences in the amount of sand, silt and clay can also affect the availability of NH_4^+ and NO_3^- ions due to adsorption to the mineral particles making them temporarily unavailable to N_2O producing processes (Sahrawat 2008).

All factors mentioned above except for soil texture are affected by soil management and agriculture practices such as tillage, type of fertilizer applied (synthetic or organic), as well as previous and current crop. These different management practices alter the soil environment and can therefore affect the amount of N_2O that can be lost from the soil to atmosphere by N_2O producing microorganisms.

1.3.2 Soil Factors Controlling N_2O in Organic and Conventional Agriculture Systems

The soil factors mentioned above have been reported to differ between organic and conventional cropping systems, and thus, emissions of N_2O from the system are expected to differ. Studies conducted by Stolze et al. (2000) and Pimentel et al. (2005) discovered that organic systems had greater amounts of soil C. Pimentel et al. (2005) also found that organic systems had greater amounts of soil N compared to conventional systems. In contrast, a study conducted by Bell et al. (2012) found at the GLTCR the organic system had lower amounts of soil C and lower amounts of soil N. This suggests that depending on the location, crop rotation, and soil management practices may affect the differences observed in organic and conventional systems. Stolze et al. (2000) and Braman (2012) found greater microbial biomass and respiration in certain organic systems compared to conventional systems. Depending on the diversity of the microbes this can lead to either an increase or decrease in N_2O emissions. Organic systems have also been observed to store greater amounts of water within the root zones and have greater water holding capacity (Lotter et al. 2003; Goh 2011). Water held in the soil for longer amounts of time is beneficial for the growing crop however this may lead to greater N_2O emission periods due to less O_2 diffusion from the atmosphere and less CO_2 and other gases out of the soil.

1.4 Nitrous Oxide from Agriculture Systems

1.4.1 Conventional Agriculture Systems

The intensification of agriculture systems has provided many benefits such as increasing yields to feed a growing population though this does not come without a cost. Conventional agriculture practices are now under much discrimination due to their high contributions of environmental pollution. One major contributor is from the inefficient use of N fertilizer. Nitrogen is an essential nutrient for all plants and is required in the largest amounts (Ciais et al. 2013). Nitrogen is however the most limiting nutrient within the soil for plant growth, hence the high dependence of N fertilizers. However due to time, labour, and technological constraints, N fertilizer or manure application occurs before the crop can utilize N in large amounts. The N fertilizer is then left in the soil for other N using processes such as microbial nitrification and denitrification which can be leached from the soil in the form of NO_3^- or lost as N_2O.

Conventional agriculture systems obtain their N source in many ways such as from granular urea (46-0-0), urea ammonium nitrate (UAN) which is 50% urea and 50% ammonium nitrate, ammonium nitrate (34-0-0), and anhydrous ammonia (82-0-0) (Manitoba Soil Fertility Guide 2007). The type of fertilizer used has been reported to have an effect on the amount of N_2O released from the soil after application (Tenuta and Beauchamp 2003; Asgedom et al. 2013). This is due to the form of N (NH_4^+ or NO_3^-) in which the chemical fertilizer was formulated. An NH_4^+ based fertilizer has the potential to release greater amount of N_2O due to NH_4^+ having to pass through both nitrification and denitrification. In contrast a NO_3^- based fertilizer can only be lost as N_2O from denitrification (Tenuta and Beauchamp 2003) however NO_3^- has high potential to be lost through leaching. Many studies have been conducted on N_2O release from conventional cropping systems and it has been found that after fertilizer application in the spring followed by rainfall a large N_2O emission episode occurs (Tenuta and Beauchamp 2003, Asgedom et al. 2013; Gao et al. 2015). Another large source of N_2O can be from the fall application of fertilizer during spring thaw in temperate climates (Wagner-Riddle and Thurtell 1998, Tenuta and Sparling 2011, Hu et al. 2013).

There have been many proposed practices to mitigate N_2O emissions from agriculture; such as applications of N fertilizers with urease or nitrification inhibitors, and application of slow release urea fertilizers which are coated urea granules. The coating of slow release urea fertilizers is dissolved over time from soil chemical or biological processes. Other strategies include reduced soil water logging, as well as split fertilizer applications, banding fertilizer instead of broadcast, or applying N fertilizer when the plants need it most (Hu et al. 2013). Organic agriculture has also been suggested as a practice to mitigate N_2O production from soil due to differences in the type of N sources added to the soil (Smith et al. 2007). These sources are in the form of organic matter from the application of manure, compost, or incorporation of plant residues. These N sources must first be mineralized before it can be lost as N_2O which may result in different emissions from conventional agriculture systems.

1.4.2 Organic Agriculture Systems

Organic farming is the practice of farming without the use of chemical fertilizers and pesticides and is considered a low input system. Organic systems rely more on soil management practices and natural sources for fertilizers and pest control. Organic systems obtain their N fertilizer and other nutrients from the application of animal (mainly cattle or pig) manure in solid, slurry, or composted form and/or from the plough down and incorporation of leguminous plant species such as alfalfa (*Medicago sativa*). A legume plant is one that can fix its own N from atmospheric N_2 gas due to a symbiosis with rhizobium bacteria (Rochette et al. 2004).

There are two common organic agriculture systems; annual grain only and perennial. An annual grain only is a cropping system where only annual crops are grown with one or more years of green manure grown that is incorporated as a type of fertilizer to improve soil quality (Wallace 2015). A green manure is an annual legume crop such as pea or fababean that is grown in conjunction with a cereal crop such as oats or barley. It is then incorporated or mulched when the legume crop begins to pod in order to obtain the greatest N input. The other is an organic perennial system where a forage crop; most commonly a legume forage such as alfalfa is grown for two or more years and is then ploughed / incorporated into the soil (Bell et al. 2012).

Organic food product demands have been increasing 20 – 25% per year since 1990 worldwide (Lotter 2008). In Canada it was estimated that in 2009 the total area of land used for organic farming was 700,000 ha (Agriculture & Agri-Food Canada 2013). Land area under organic agriculture has now increased to just over 900,000 ha in 2014 and worth upwards of $2 billion (Agriculture & Agri-Food Cananda 2013; Canada Organic Trade Association 2016). The increase in demand and acreage has made organic agriculture one of the fastest growing sectors in Canada's agriculture industry. The demand for organic products is driven by the belief that organic products are healthier, tastier, and is more environmentally friendly when compared to conventional agriculture systems (Lotter 2008).

However there has been much criticism on organic agriculture for its lower yields and how it is supposed to feed a growing population. Another offset of organic agriculture is the reliance on tillage for weed control which can contribute to soil erosion and greater fossil fuel consumption (Johnson et al. 2012). Johnson et al. (2012) stated that the lower yields would offset the positive environmental impacts from organic farming.

1.4.2.1 Nitrogen sources in organic agriculture systems

Since there is no use of chemical fertilizer in organic cropping systems, these systems must obtain their N from natural sources. As mentioned above these sources include animal manure, composted animal manure, and the use of legume crops. These N sources can provide a large amount of N to the soil in the form of plant residues (Rochette et al. 2004). The amount of N that can be provided to the next crop depends on the timing of the of stand termination, method of termination, and age of stand if growing a legume forage (Ball et al. 2007; Manitoba Soil Fertility Guide 2007). Both the timing and method of termination can affect the amount of N_2O released from legume sources (Ball et al. 2007). Manure or compost applications can occur once or more over the course of a rotation. Just like with the incorporation of legumes the composition, timing and method of application will determine how much N will be available to the subsequent crop.

1.4.2.2 Organic agriculture systems and N_2O emission

Organic cropping systems obtain their N source from the incorporation of a legume plant and / or from the application of animal manures. This N source differs from conventional sources by N being tied up in the residues and therefore must be first mineralized before it can be nitrified or denitrified and released as N_2O by microorganisms. Nitrogen fertilizers used is conventional systems are applied in the form of NH_3, NH_4^+ or NO_3^- and is readily available to N_2O producing soil microorganisms. This difference could result in different amounts of N_2O released from the soil; however there are few reports on N_2O release from organic agriculture.

The majority of N_2O emissions that occurs from organic systems come from the microbial breakdown of the added compost, animal manure or from the plough down of forage legumes / green manure into the soil. It has been suggested that higher soil C within the soil from the addition of manure or from the plough down of leguminous crops may increase N_2O emissions since soil C is a major controlling factor to its release (Li et al. 2005; Nadeem et al. 2012).

Organic agriculture can be a potential mitigation strategy for reducing GHG emissions in agriculture (Smith et al. 2007). This finding has been attributed to fewer inputs needed in the system such as fertilizers and pesticides. The absence of these applications means less energy consumption and therefore less GHG emissions from operating tractors, applicators, production, and transportation (Hoeppner et al. 2005). However yields in organic cropping systems are on average 30% lower than in conventional cropping systems (Stanhill 1990; Hoeppner et al. 2005;

Pimentel et al. 2005). These lower yields can offset the environmental benefits of having lower GHG emissions than conventional systems (Johnson et al. 2012). This is not always the case: organic cropping systems have been reported to have equal or greater yields than conventional systems (Stanhill 1990; Entz et al. 2001; Pimentel 2005). Even though organic yields can sometimes be slightly lower, the economic return resulted with either the same or higher income than conventional returns due to the higher market place price for organic grains and less input costs (Pimentel et al. 2005). With greater research, increased yields in organic systems may be attainable.

1.4.3 Comparison of N_2O emissions between organic and conventional agriculture systems

Few studies have been conducted comparing N_2O emissions between organic and conventional cropping systems (Flessa et al 2002; Petersen et al. 2006; Johnson et al. 2012; Nadeem et al. 2012; Aguilera et al. 2013); however, to my knowledge none have been reported for Canada. The studies conducted have found that organic cropping systems may emit more or less N_2O than conventional cropping systems. This suggests that these differences in findings may be on a farm to farm basis or other factors such as crop rotation or climate may cause these differences.

According to Flessa et al (2002), Petersen et al. (2006) and Aguilera et al. (2013) organic cropping systems with the absence of synthetic N fertilizer have been shown to lower N_2O emissions, however a study by Nadeem et al. (2012) contradicted this and reported greater N_2O emissions. Johnson et al. (2012) reported that both organic and conventional systems had similar N_2O emissions when emissions were scaled to yields. This was also observed by Flessa et al. (2002). They stated that even though lower N_2O emissions occurred when yield scale comparisons were made, emissions per kg of crop output were greater in organic systems. Which Johnson et al. (2012) states may offset the environmental benefits of lower emissions observed on an area basis. A global meta-analysis conducted by Skinner et al. (2014) comparing N_2O emissions between organic and conventional cropping systems also concluded that organic systems do emit less N2O on an area basis however not on a yield basis. From the studies mentioned above conducted on organic and conventional agriculture on N_2O emissions some weaknesses have been suggested when estimating emissions from organic systems in Canada.

The studies listed above were conducted in areas with different climates but they do not include all types of climate where agriculture occurs. The study by Flessa et al. (2002) was conducted in Germany, Petersen et al. (2006) was conducted in five different European countries, Aguilera et al. (2013) in the Mediterranean, Nadeem et al. (2012) was conducted in Norway, and Johnson et al (2012) was conducted in Minnesota, USA. This does give a broad spectrum of different climates, but only two countries in the Peterson et al. 2006 study and the study conducted by Johnson et al. (2012) have temperatures consistently below freezing and has frozen soils for a sizeable portion of the year. It has been reported by Wagner-Riddle and Thurtell (1998) that spring thaw can be a significant source of N_2O and should be considered in N_2O budgets.

Due to the nature of N sources in organic systems Skinner et al. (2014) suggest that other variables such as soil type may play more of a role in the amount of N_2O release from organic systems. The above mentioned studies were all conducted on a loamy soil. The soil at GLTCR is a heavy clay soil which has greater water holding capacity and may result in different N_2O emissions. To reduce agricultural N_2O emissions, accurately determining N_2O emissions from all land management types in all climates is needed. This study will help resolve these discrepancies and aid in mitigation strategies for N_2O emissions in agriculture systems.

1.5 Hypothesis:

The hypothesis for this study is that the fall alfalfa plough down in organic systems will produce a N_2O emission event. I have utilized the Glenlea Long Term Crop Rotation and Management study site to conducts the research for this thesis. After plough down and during spring thaw, it is expected the alfalfa will produce an emission episode due to mineralization of the residues, however yield and area scaled emissions will be close or equal to the conventional system. The following crops, hard red spring wheat will, produce a significant N_2O emission early in the growing season. Cumulative emissions will be equal to or lower on an area scaled, but not on a yield scaled basis due to lower yields in organic systems.

1.6 Structure of Thesis:

The format of this thesis is set up to be published in the Journal Agriculture, Ecosystems and the Environment. Data for this study was collected during two site years in 2014 and 2015, both years are presented in the following data chapter. Following the data chapter is a general discussion and conclusion highlighting this thesis's contribution to knowledge on organic systems, and looking towards the future for N_2O emissions in organic and conventional systems in light of climate change.

2.0 Nitrous Oxide Emissions from a Long-term Organic and Conventional Cropping System Comparison in Manitoba, Canada.

2.1 Abstract

Agriculture is the major contributor of global N_2O emissions due to nitrogen (N) additions to soil, primarily from the use of synthetic and animal manure N sources. Perennial legumes (e.g. alfalfa) are used in organic cropping systems to provide N and other nutrients to the soil for subsequent crops. Many studies have been conducted on soil N_2O emissions in agriculture; however the amount of N_2O emitted from organic production systems, particularly from the fall plough down of alfalfa to provide N for subsequent crops, is not well understood. In this study, the Glenlea Long-Term Organic Crop Rotation Study near Winnipeg was used to compare N_2O emissions of conventional annual grain and organic mixed forage-grain systems. The static vented chamber method was used to determine N_2O emissions for the 2014 and 2015 crop years. Organic wheat and alfalfa emitted less N_2O than conventional wheat and soybean. There was no N_2O emission episode shortly after fall plough down of alfalfa in 2014 or during spring thaw in 2015. The 2015 plough down of alfalfa caused a slight N_2O emission episode with a maximum flux of 14 g N_2O-N/ha/day. In both study years, yield-scaled emissions were also lower in the organic cropping system compared to the conventional systems. The low N_2O emissions observed in the organic system were not due to low soil nitrate (NO_3^-) concentrations as levels were higher after alfalfa plough down than following fertilizer addition in spring in the conventional system. In conclusion, considering results of two study years, a long-term organic production system in the Red River Valley that relies on fall plough down of alfalfa to provide N resulted in lower N_2O emissions than conventional cropping using urea fertilizer.

Highlights:

- Daily and cumulative N_2O emissions in organic and conventional agricultural systems in Manitoba, Canada.
- Low to no N_2O emissions after the fall plough down of alfalfa in organic systems.
- Lower hard red spring wheat yields in the organic systems; however yield scaled emissions was lower for both years.
- Greater NO_3^- intensity in the organic system but low N_2O emissions.
- Lower N_2O emissions overall in the organic cropping system compared to the conventional system.

Key words: nitrous oxide, organic, agriculture, greenhouse gases

2.2 Introduction

Nitrogen (N) additions to the soil (e.g. inorganic fertilizers, livestock manures) induce soil nitrous oxide (N_2O) emission (Tenuta and Beauchamp 2003; Asegedom et al. 2013; Gao et al. 2013) contributing a major source of anthropogenic N_2O to the atmosphere. Approximately 70% of Canadian anthropogenic N_2O is from agriculture soil and manure management (Environment Canada 2016). This is a concern because N_2O is a potent GHG with 298x the global warming potential of carbon dioxide (CO_2) (IPCC 2013). Numerus studies have examined N_2O emissions after synthetic N fertilizer application in Manitoba (MB) and elsewhere in the Canadian Prairies (Asegedom et al. 2013; Gao et al. 2013; Gao et al. 2015) but none report for organic cropping systems. Determination of soil N_2O emissions from all management systems and N application types is needed to accurately develop mitigation strategies as well as in the development in regional and national GHG inventories.

Organic crop production is one of the fastest growing sectors in Canadian agriculture expanding from 695,000 ha in 2009 to over 900,000 ha in 2014 (Agriculture and Agri-Food Cananda 2013; Canada Organic Trade Association 2016). Demand for organic products has also rapidly increased 20 – 25% annually since 1990 (Lotter 2008). Organic agriculture is considered in some cases to be a low-input form of agriculture because it does not use synthetic fertilizer and pesticides; however the system still relies heavily on tillage for weed control (Johnson et al. 2007; Smith et al. 2007). Crops in organic systems obtain nutrients (more importantly N for this study) from the application of animal manure or compost, incorporation of green manure, or forage legumes such as alfalfa (*Medicago sativa*) or a combination of all three which can provide adequate amounts of N (Entz et al. 2001). The mineralization of organic N from these sources may be slower than the availability of inorganic N from synthetic N fertilizers (Agehara and Warncke 2005; Asgedom et al. 2013).

Soil N_2O emissions are produced by bacteria through the processes of nitrification, nitrifier denitrification and denitrification (Wrage et al. 2001; Norton 2008; Coyne 2008). The bacterial processes mentioned above are stimulated by the presence of inorganic N (NH_4^+ and NO_3^-). Nitrification is the process where NH_4^+ is oxidized into NO_3^- under aerobic conditions (Norton 2008). Nitrous oxide is released from nitrification from the chemical breakdown of hydroxyl amine (NH_2OH) (Wrage et al. 2001). Dentrification is the process where NO_3^- is reduced back to N_2 under anaerobic conditions. Nitrous oxide is released when semi-anaerobic conditions occur in the soil causing incomplete reduction of NO_3^- (Wrage et al. 2001; Coyne 2008). Nitrifiers can also perform denitrification known as nitrifier denitrification. In low oxygen (O_2) conditions nitrifiers will reduce NO_2^- to N_2O or N_2 (Wrage et al. 2001). Less inorganic N in the soil when the crops cannot utilize large amounts of N could result in lower N_2O emissions from organic agriculture systems.

There are primary and secondary drivers for soil N_2O production. Inorganic N is just one of the primary drivers for soil N_2O release. Other primary drivers include soil moisture and temperature, soil carbon (C) content, O_2 availability (Gao et al. 2014). Secondary drivers are ones that affect the primary drivers such as soil management and crop rotation (Gao et al 2014). Nitrification is an aerobic process meaning O_2 must be present. Greater soil moisture will result in less O_2 availability and inhibit NH_4^+ oxidation and N_2O released from nitrification (Norton 2008). Denitrification is an anaerobic process meaning O_2 must be absent in order for NO_3^- to be fully reduced (Coyne 2008). In conditions with some O_2 availability NO_3^- will only be reduced to NO or N_2O. Soil C can increase N_2O emissions by provided an electron source to denitrifiers and increasing their activity (Li et al. 2005; Coyne 2008). Additions of C to the soil can also affect soil properties such as bulk density, porosity, oxygen content and water holding capacity which can affect N_2O production (Li et al. 2005). Crop rotation can affect N_2O emissions due to differences in N requirements. Greater amounts of N fertilizer applied can result in greater N_2O emissions (Synder et al. 2009). Soil tillage can alter the soil structure in fields breaking up large soil aggregates resulting in smaller pores spaces which can be more conducive to an anaerobic environment (Coyne 2008). This may result in different N_2O emissions from different soil management practices.

Soil management practices vary between organic and conventional agriculture due to the constraints of suitable nutrient sources that can be applied organic systems. Organic systems in the Canadian Prairies for example, can include legume forages in their rotations where the soil is undisturbed for a few years and large amounts of C and N are introduced to soil from the plough down of the forage in late summer (Entz et al. 2001; Entz et al. 2002). Conventional systems rely more on annual crops. It has been reported that the factors mentioned above differ between organic and conventional management systems (Pimentel et al. 2005; Bell et al. 2012; Braman 2012). Organic systems tend to have greater topsoil C, are able to hold more moisture, greater microbial activity, and in some cases greater soil N (Stolze et al. 2000; Pimentel et al. 2005;

Braman 2012). These attributes tend to point in the direction conducive to N_2O production however a search of peered reviewed studies shows varying results.

It is uncertain if organic crop production systems differ in the amount of N_2O emissions from conventional ones. Flessa et al (2002), Petersen et al. (2006), and Aguilera et al. (2013) reported lower N_2O emissions from organic production systems, but Johnson et al. (2012) and Nadeem et al. (2012) reported greater N_2O emissions. To my knowledge, a comparison of N_2O emissions of an organic and conventional production in Canada has not been published in a peer-reviewed journal. The Flessa et al. (2002), Petersen et al. (2006), Nadeem et al. (2012) and Aguilera et al. (2013) studies were conducted in Europe and Johnson et al. (2012) in Minnesota, USA. Work on N_2O emissions in organic systems in Atlantic Canada has been conducted. A PhD graduate thesis monitored emissions following the fall and spring incorporation of red clover (*Trifolium prantense* L.) during the off season (September – June) for two years. However no comparison to a conventional system was made.

Organic agriculture is considered by some to be a N_2O mitigation strategy however one discrepancy when comparing N_2O emissions are yields which may offset the environmental benefits of lower emissions (Smith et al. 2007; Johnson et al.2012). On average organic systems yield 30% less than conventional systems (Hoeppner et al. 2005; Pimentel et al. 2005; Goh 2011). However, studies have reported that organic systems can out yield conventional systems (Stanhill 1990; Entz et al. 2001; Pimentel et al. 2005). It has also been noted that in years of drought, organic systems have more consistent yields compared to conventional counter parts (Seufert et al. 2012). In a changing climate where greater droughts and crop stresses are predicted, organic system environmental benefits and lower input costs there is now an increasing interest to switch to organic production (Entz et al. 2001; Thiessen Martens et al.

2015). However, there is little knowledge of soil N_2O emissions from organic crop production systems in the Canadian Prairies.

In the current study, the Glenlea Long-Term Rotation and Management study site at Glenlea, Manitoba was used to compare N_2O emissions from an organic cropping systems and conventional cropping systems. The first objective of the study was to compare N_2O emissions from their legume cropping phases; alfalfa (*Medicago sativa* L.) under organic and soybean (*Glycine max* L.) for the conventional system. Further it was to determine if fall plough down of alfalfa differs in the amount of N_2O released compared to synthetic fertilizer. The second objective of the study was to compare N_2O emissions on an area (g N_2O-N ha^{-1}) and yield-based (g N_2O-N Mg^{-1} grain) between cropping systems for the same crop, hard red spring wheat (*Triticum aestivum* L.).

2.3 Materials and Methods

2.3.1 Site Description

This study was conducted at the University of Manitoba's Glenlea Long Term-Crop Rotation (GLTCR) Study which was established in 1992. The GLTCR is western Canada's oldest organic and conventional cropping system comparison study. The study site is located 20km south of Winnipeg at the National Centre for Livestock and the Environment and the University of Manitoba Glenlea Research Station (49.39 N and 97.7 W). The long-term annual (1981-2010) mean precipitation is 542 mm with 450 mm falling as rain. The long-term annual mean temperature is 2.8 ˚C (Environment Canada 2015).

2.3.2 Experimental Design

The experimental design of GLTCR site is a two treatment (rotation x management) randomized complete block design with three replicates. There are two rotations; annual grain only consisting a rotation of flax (*Linum usitatissimum* L.) – oat (*Avena sativa* L.) –soybean – spring wheat and a perennial grain-forage rotation consisting of flax –alfalfa - alfalfa- spring wheat. Management is conventional (synthetic fertilizer, herbicide, fungicide) and organic (green manure, compost, no synthetic agrochemicals). In the last few years the organic alfalfa plots have also been seeded with timothy (*Phleum pretense* L.) and red clover to help with weed competition. The plots are in a fully phased rotation meaning that each crop is grown each year. Plots are 4 x 28m for conventional and 4 x 12m for the organic treatments, the latter being smaller due to being split for treatments with and without soil dairy compost application. For the current study the plots that receive the compost application were monitored. Organic and conventional plots are spaced at least 15 m away from each other to reduce fertilizer and pesticide transfer (Bell et al. 2012).

The treatment design of the experiment is a 2x2 factorial design with two treatments and three replicates. The treatments are i) hard red spring wheat and ii) legume both under conventional and organic management. In the organic-perennial system the legume crop is perennial alfalfa and in the conventional-annual system the legume crop is soybean (24-10RY). The hard red spring wheat (CV. Waskada) is under both conventional-annual and organic-perennial management. In the conventional system the wheat receives a spring broadcast/incorporation application of granular urea and the organic spring wheat follows alfalfa in the organic rotation and the fall plough down of alfalfa is the N fertilizer source in the organic system.

2.3.3 Soil Classification:

The soil at GLTCR is a Rego-Black Chernozem apart of the Red River soil association and has two sub-classifications: Osborne clay in micro depressions and Red River clay elsewhere. Red River clay soils have a dark gray to black "A" horizon 20 -25cm thick with granular aggregates, and weakly prismatic structure; very sticky when moist and hard when dry (Manitoba Soil Survey 1975). Osborne clay soils have a dark grey "A" horizon 6-15cm; granular aggregation in structure; sticky when wet and hard when dry (Manitoba Soil Survey 1975). The soil consists of 660, 260, 90 g kg^{-1} of clay, silt, and sand, respectively, with an organic matter content of 55 g kg^{-1} (Turmel et al. 2009; Natural Systems Agriculture 2012). The land capability for agriculture of the site is Class 2, imperfectly drained with minimal erosion, and level to nearly level (Soils of the Municipality of Richot 2011). Natural vegetation for the Red River soil association is tall grass prairie, sedges, grasses, aspen and willow (Manitoba Soil Survey 1975).

2.3.4 Field Operations:

Conventionally managed plots were soil sampled in the fall prior to seeding to determine soil nutrient status and was used along with soil test recommendations in the Manitoba fertility guide to determine spring fertilizer rate (Table 2.1). Organic plots were managed with no external inputs except for the application of composted cattle manure in the alfalfa plots every 7-10 years. In the current study compost was applied to the alfalfa treatments in 2014 at a rate of 2 tons dry matter/ha^{-1}.

In both 2014 and 2015 prior to seeding the conventional spring wheat plots received an urea (46-0-0) and monoammonium phosphate (MAP) (11-52-0) fertilizer that was broadcast at a rate of 101 kg N ha^{-1} followed by harrowing and then incorporated by rototilling of the plots on May 15 and April 29, respectively (Table 2.1). The organic spring wheat plots were also rototilled and harrowed on the same dates stated above, however with no fertilizer application. Waskada hard red spring wheat was then direct seeded in both management systems at a rate 100 kg ha^{-1} with a row spacing of 15 cm on May 16 and 120 kg ha^{-1} on April 30 in 2014 and 2015, respectively. Soybeans (Dekalb 24-10RY) was seeded on May 28 and May 25 in 2014 and 2015, respectively at a rate of 90 kg ha^{-1}; after seed bed preparation by rototilling and harrowing with no fertilizer application. Roundup® herbicide (a.i. glyphosate) was applied to the conventional soybean plots on June 2 and June 11 in 2014 and 2015, respectively at a rate of 3.5 L/ha. Horizon® herbicide (a.i. clodinafop-propargyl) was applied to conventional wheat plots on June 5, 2014 only. Wheat and soybeans were harvested in the fall using a small plot combine harvester on September 17 and September 26 in 2014 and 2015, respectively (Table 2.1) followed by rotor-tilling to incorporate residues. Wheat and soybeans were harvested the same as in 2015, but harvest occurred earlier on August 20 and September 23, respectively. Alfalfa (AC Caribou) was seeded in early May at a rate of 15 kg ha^{-1} mixed with 2.5 kg ha^{-1} of timothy grass and red clover. In 2014 alfalfa, timothy, and red clover was seeded in early May at the same rate, but the alfalfa variety used was 4020 MF. Alfalfa was cut and removed for hay twice in 2014 and 2015 on June 26 and August 15, and June 16 and August 5, respectively. Alfalfa termination by rotovation occurred on September 23 and September 3 in 2014 and 2015, respectively. Alfalfa was then rototilled again to ensure termination of forage in both 2014 and 2015 on October 15 and September 3, respectively. Biomass samples were taken in all treatments before harvest, all alfalfa removals, and before alfalfa plough down (Table 2.1).

Table 2.1. Crop, nitrogen (N) source, application date, application rate, and harvest date in 2014 and 2015.

Management / Crop	N source	Application date (DOY)	Application rate	Harvest date (DOY)‡
2014			--- N kg ha^{-1}---	
Conventional Soybean	BNF†	---	---	269
Conventional Wheat	Urea (46-0-0), MAP(11-52-0)§	135	101	260
Organic Wheat	Preceding fall alfalfa plough down	---	---	260
Organic Alfalfa	BNF & composted cattle manure	156	61.6*	1st 177 2nd 227 3rd 269
2015				
Conventional Soybean	BNF	---	---	266
Conventional Wheat	Urea (46-0-0), MAP (11-52-0)	119	101	232
Organic Wheat	Preceding fall alfalfa plough down	269$^{\phi}$	92	232
Organic Alfalfa	BNF & composted cattle manure in 2014	---	---	1st 167 2nd 215 3rd 246

†Crop biological nitrogen fixation.
‡Harvest dates for organic alfalfa indicate cuttings for hay and removed from the plot except for the 3rd harvest date where alfalfa is ploughed into the soil.
§MAP, Monoammonium phosphate
ϕ Application date for organic wheat in 2015 in reference to the 2014 fall alfalfa plough down.
* Compost analysis in Appendix.

2.3.5 Nitrous Oxide Sampling:

Soil N_2O emissions were monitored using a static vented chamber method procedure (Tenuta et al. 2010; Figure 2.1). Four PVC collar chambers (20cm in diameter and 10cm in height) were inserted approximately 5cm into each plot and removed and reinserted for field operations (i.e. seedbed preparation, seeding, plough down of alfalfa). The top of the chamber above the soil has four screws inserted into the chamber with rubber inner tubing stretched around the edges as a gasket to ensure an air tight seal. Lids of PVC, 22 cm in diameter covered with inner tube, having a rubber septum for gas sampling, a plastic venting tube, and topped with reflective aluminum tape pressed to the collar top using rubber bands during gas sampling.

Gas samples were taken using plastic 20 ml syringes at time 0, 15, 30, and 45 minutes after lid placement. The syringe was inserted into the rubber septum and gas was extracted then pushed back in the chamber to ensure thorough mixing within the chamber (Figure 2.1). A 20ml sample was taken from the chamber and inserted into twice pre-evacuated helium (He) flushed 12ml vials (Extainer Labco Ltd) topped with silicone sealant. Gas samples were then transported back to the laboratory at the University of Manitoba and stored until analyses. Gas analysis was conducted using gas chromatography at the University of Manitoba. Samples were analyzed for N_2O using a gas chromatograph equipped with an electron caption detector (Varian CP-3800). Samples of 2.5 ml were obtained from the vials via a Combi-PAL auto-sampler (Combi-PAL; CTC Analytics, Zwingen, Switzerland). Calibration of the chromatograph was done using standards of pure N_2O gas placed at every 10^{th} sample (Welders Supplies). Respiration as carbon dioxide fluxes were also estimated to inform on biological activity of soil using gas chromatography with a thermal conductivity detector. Following the analyses by gas chromatography N_2O (g N_2O-N ha^{-1} day^{-1}) and CO_2 (g CO_2-C ha^{-1} day^{-1}) emissions rates were then calculated using the HMR program in R computer language (R Development Core Team 2008) to determine linear and non-linear regression to obtain the daily flux value.

Figure 2.1: Static vented chamber, syringe needle, and vials for greenhouse gas sampling at the Gleanlea Long-Term Crop Rotation.

Sampling occurred two to three times a week before and after fertilizer application; May – July in 2014 and April – July in 2015 (Figure 2.2 and 2.3). Sampling occurred one to two times a week during July and August due to drier soil conditions and expected lower emissions. After the plough down of alfalfa in both years, sampling frequency increased to two to three times a week until mid-October and then once a week until soil freeze up mid to late November when snow covered the majority of the chambers. Spring thaw of 2015 began in early March with sampling started on March 11 two to three times a week until seeding at the end of April. Gas samples were extracted on total of 64 sampling dates in the 2014 crop year from May 14 2014 to April 30 2015 and 53 for the growing season from May 2015 to November 2015. Cumulative emissions were calculated for individual chambers for each 2014 and 2015 growing season by linear interpolation and summation of calculated flux emission between sample dates from May 14, 2014 – April 30, 2015 and from May 1 – November 10, 2015.

Figure 2.2: Greenhouse gas sampling using a vented static chamber.

Figure 2.3: Chambers in organic alfalfa plots after fall plough down of alfalfa.

2.3.6 Weather and Soil Monitoring:

Annual rainfall and air temperature data (Figure 2.4) were measured at the Trace Gas Manitoba (TGAS-MAN) study site located 1 km North West of GLTCR on the same station. At each gas sampling date, air temperature was taken 60 - 90 cm above the ground in the shade using a Traceable Longstem Thermometer (Fisher Scientific Canada, Nepean, ON). Soil volumetric moisture content (%) and soil temperature (˚C) were taken at each sample date in the top 5 cm on the soil using a WET sensor (Delata Devices; Cambridge England) taken within 30cm of the chamber.

Soil samples for nutrient analysis were collected during the growing season until soil freeze up in 2014 and from spring thaw until freeze up in 2015. Samples to 15 cm were taken with a 3.8 cm diameter Dutch auger. A sample was taken in the general area around each chamber; making a composite of four samples per plot. Soil samples were also taken at the end of the growing season in the top 15 cm and in the 15 to 60 cm soil depth to determine residual N in the root zone. Samples were then put in plastic bags and then in an insulated chest, brought back to the University and placed at -20˚C until analysis. Samples were thawed and then analyzed for gravimetric moisture content (GMC), ammonium (NH_4^+), nitrate (NO_3^-), and total extractable carbon (TEC).

Gravimetric moisture content was determined by drying a 10g sub-sample, placed in an oven at 105˚C for 24h and then weighed again to aid in nutrient status determination. Gravimetric moisture content was determined using equation 1.

$$\frac{[(pan+wet\ soil)-pan]-[(pan+dry\ soil)-pan]}{[(pan+dry\ soil)-pan]} = \text{kg water / kg dry soil} \qquad (1)$$

Extractable soil NH_4^+ and NO_3^- concentrations were determined from 5g sub-samples placed in a plastic centrifuge tube with 25ml of 2M KCl and shaken for one hour on a reciprocating shaker at 150 epm. The tubes were then centrifuged for 3 minutes and 30 seconds at 3000 rpm. A 15ml sub sample of the supernatant was taken and placed in a scintillation vial and frozen until analyzed for NH_4^+ and NO_3^- using a Technicon II Auto-analyzer using the Berthelot reaction and Cu-Cd reduction to NO_2^- with the formation of diazo-compounds, respectively.

Cumulative NO_3^- concentrations used for linear regression with cumulative N_2O emissions were calculated by linear interpolation using equation (2). All totals were then summed together for cumulative NO_3^- concentrations.

$$\left(\frac{(1st\ coil\ sample\ nitrate\ conc - 2nd\ Soil\ sample\ NO3\ conc)}{(1st\ soil\ sample\ date - 2md\ soil\ sample\ date)}\right) + 1^{st} \text{ soil sample } NO_3^- \text{ conc} \qquad (2)$$

Total extractable carbon was extracted using a 5g sample of soil into a centrifuge tube with 25ml of 0.5 M K_2SO_4 and shaken on a reciprocating shaker for one hour at 150 epm. The samples were then centrifuged at 3000 rpm for 3 minutes and 30 seconds. A 15ml sample of the supernatant was then pipetted and put into a scintillation vial and analyzed using a Technicon II Auto-analyzer using the Phenolphthalein method.

2.3.7 Yield and Biomass Analysis:

Plant biomass samples were taken from all crops for N biomass analysis. Two samples were taken in each plot using a hand held sickle and 50 cm x 50 cm quadrat. Samples were taken for both wheat and soybean prior to harvest on August 15 and September 26, 2014, respectively. Alfalfa was cut twice during the growing season with two biomass samples taken in each plot using a sickle and 50cm x50cm quadrate prior to each cutting and before the alfalfa plough down (Table 2.1). In 2015 mature wheat and soybeans were harvested on August 20 and September 23, respectively. Biomass samples were taken before harvest for both spring wheat and soybeans on August 17 and September 14, respectively. Alfalfa plots were cut twice during the growing season again in 2015 with biomass samples taken prior to cutting, as well as before the fall plough down (Table 2.1). The samples were then placed in a paper bag and brought back to the laboratory placed at 48°C until dry, then ground using a Wiley Mill. The ground samples were put into plastic Ziploc bags and sent to Agvise Laboratories for analysis of N concentration. All samples were weighed before grinding. After harvest, grain was brought to the laboratory where it was cleaned, dried at 65˚C for 72h and weighed. Dried grain samples were ground in a Wiley

Mill and sent to Agvise Laboratories for analysis of N concentration. In the current study grain yields are presented on a standard test weight for wheat and soybean using equation (3).

$$\frac{(100-8)}{(100-13.5)}) * yield \text{ Mg ha}^{-1} \qquad (3)$$

Nitrous oxide emissions were also compared on a yield basis. Comparing how much N_2O was emitted per kg of grain using equation (4).

$$\text{Cumulative } N_2O \text{ g N ha}^{-1} \text{ day}^{-1} / \text{Yield Mg ha}^{-1} = \text{Emission Intensity g N kg}^{-1} \qquad (4)$$

2.3.8 Statistical Analysis:

Statistical analysis was carried out using Statistical Analysis System 9.4 software (SAS Institute Inc. 2014). Analysis of variance ($\alpha = 0.05$) was conducted using Proc Mixed and LSD analysis for cumulative N_2O emission, nitrogen removed (N_h), and N_2O emission intensity (EI). Fixed effects were management, crop and year. Random effects were plot replicates and chambers within plots. Data that did not meet the test for normality (Shapiro-Wilks) prior to analysis were, transformed by adding two followed by $\log_{10}$ transformation. The association between $\sum N_2O$ and NO_3^- intensity between managements was determined using linear regression analysis. Arithmetic mean values for untransformed data are reported in tables and figures. Differences among relationships or treatment means were declared to be significant at $P < 0.05$.

2.4 Results

2.4.1 Weather Conditions:

Air temperatures and precipitation taken throughout the growing season were recorded at the TGAS-MAN research site at the Glenlea Station located 1km North East of the study site. Mean air temperature at GLTCR in 2014 was 1.2˚C cooler than the long term mean (1981-2010) of 2.8˚C. In 2015 the mean temperature was 4°C warmer than the long term mean (Environment Canada 2015). Annual total precipitation was 366 mm in 2014 and 510 mm in 2015, both 2014 and 2015 had less precipitation than the long-term mean (1981-2010) of 542 mm for Glenlea (Environment Canada 2015).

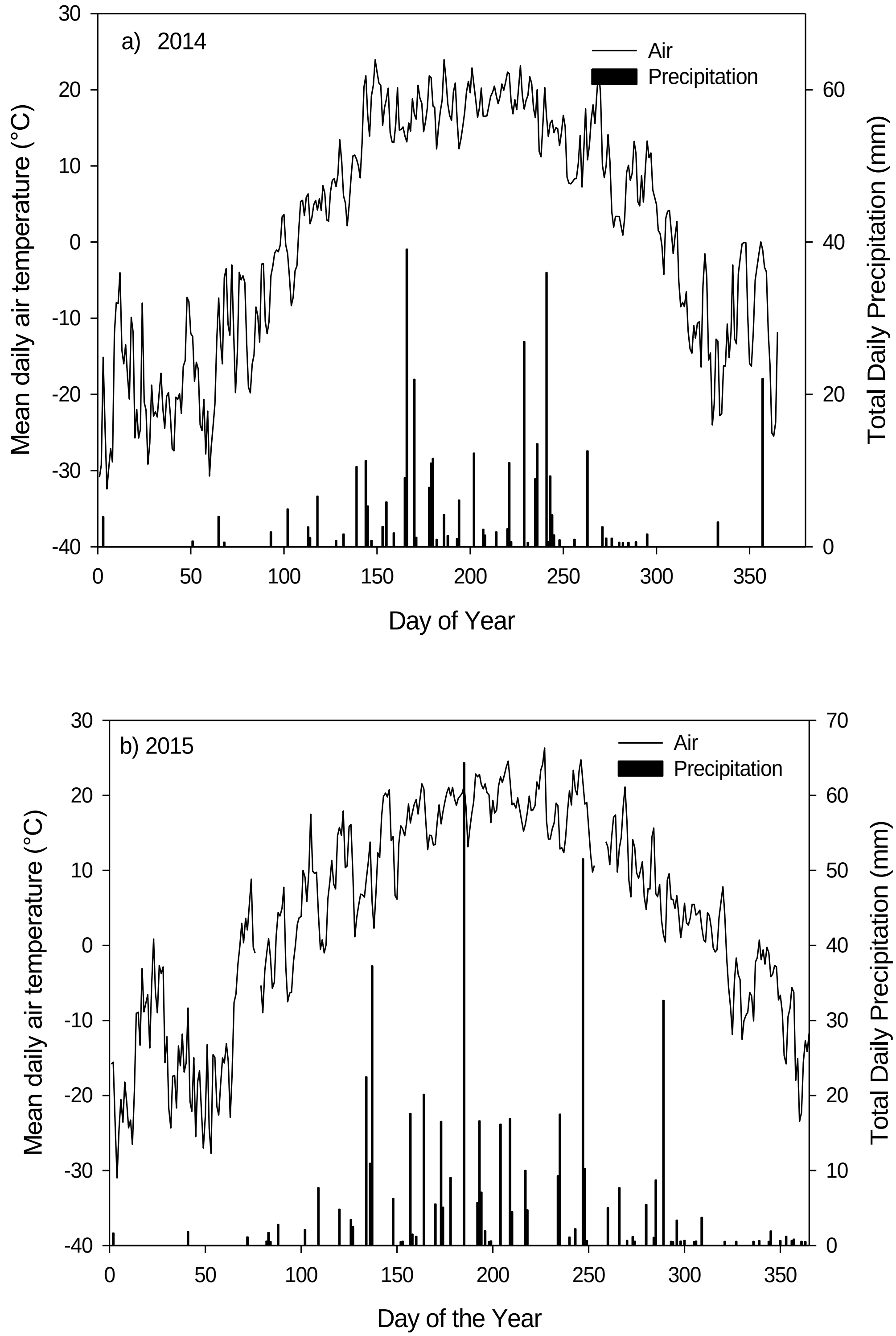


Figure 2.4: Mean daily air temperature (°C) and total daily precipitation (mm) for a) 2014 and b) 2015 crop years.

2.4.2 Nitrous Oxide Emissions:

During the 2014 growing season two N_2O emission episodes occurred following application of urea fertilizer to the conventional wheat (Figure 2.5). The first episode occurred eleven days after fertilizer application (DOY 146) lasting 7 days with the greatest peak flux of 47.5 g N ha^{-1} day^{-1}.The second emission episode occurred on DOY 167 thirty-two days after fertilizer application and lasted three days. The second episode was larger than the first with a maximum peak of 69.7 g N ha^{-1} day^{-1} and was most likely due to rainfall of 9 mm on DOY 165 and 39 mm on DOY 166 (Figure 2.4a). Emission episodes stopped five weeks after N application.

Two low emission episodes occurred in the organic wheat (OW) that was seeded in the 2013 fall plough down of alfalfa plots (Figure 2.5). The first emission episode lasted seven days with a maximum of 8.9 g N ha^{-1} day^{-1} on DOY 146. The second emission episode occurred on DOY 167 and was lower than the first with a maximum flux of 4.4 g N ha^{-1} day^{-1} lasting three days. Like in the conventional wheat (CW) the second emission episode was most likely initiated by rainfall as stated above.

Both the conventional soybean (CS) and organic alfalfa (OA) had one emission episode in 2014 starting on DOY 167. However the OA episode lasted until DOY 174 whereas the CS ended on DOY 170 (Figure 2.5). The OA emitted a lower flux of N_2O with a maximum of 8 g N ha^{-1} day^{-1} compared to the CS with a maximum flux of 43 g N ha^{-1} day^{-1} both occurring DOY 167 following rain over the previous two days (Figure 2.4a).

The 2014 plough down of OA occurred on DOY 269 with a second cultivation occurring on DOY 288 to ensure termination (Figure 2.5). No emission episode was observed after fall plough down with a maximum flux of 0.5 g N ha^{-1} day^{-1} occurring on DOY 272 even though soil N concentration were greater than all other treatments (Figure 2.7). No distinct emission episode occurred during the spring thaw of 2015 from the fall plough down of OA with a maximum flux of 1.8 g N ha^{-1} day^{-1} occurring on DOY 435. No emission episodes occurred in CS, CW, and OW during the spring thaw (Figure 2.5).

Carbon dioxide was analyzed as well when gas samples were run through the gas chromatograph for N_2O to aid as an indicator of microbial activity. Low CO_2 emissions occurred after the fall plough down of alfalfa.

In 2014, soil VMC in the top 5 cm of soil was consistently lower in the organic treatments compared to the conventional treatments. After the fall plough down of alfalfa moisture contents were much lower and stayed lower than all other treatments.

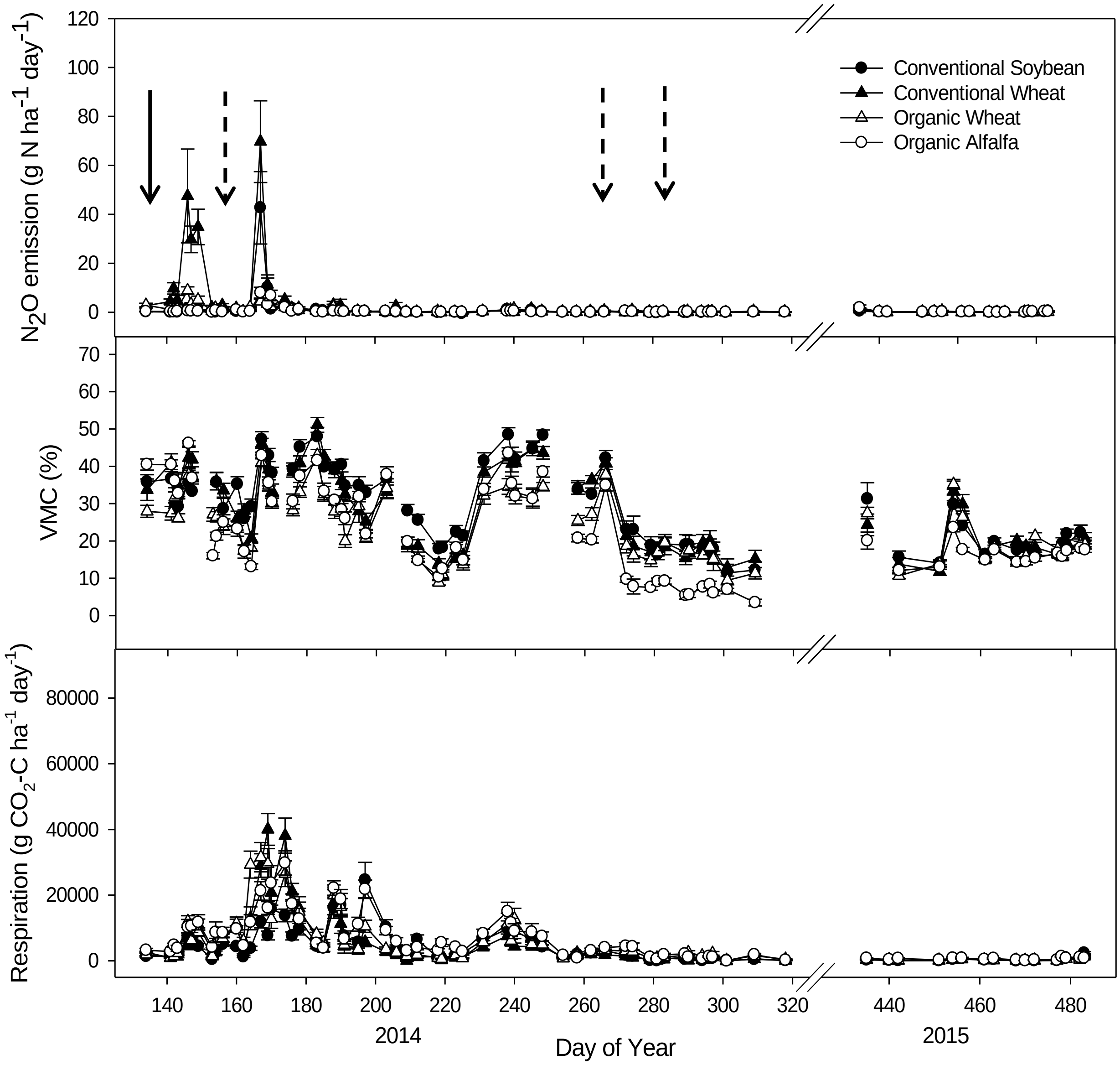


Figure 2.5: Mean daily crop year (May 2014 – April 2015) nitrous oxide emission, soil volumetric moisture content (H_2O cm^{-3} soil) 0-5cm, and respiration from conventional soybean, conventional wheat, organic wheat, and organic alfalfa. Bars indicate ± 1 standard error of the mean (n=12). Solid arrow indicates fertilizer application in conventional wheat and dashed arrows indicate alfalfa plough down and cultivation.

The 2015 growing season started approximately two weeks earlier than that of 2014, fertilizer application in CW occurred on DOY 119. Only one emission episode occurred in 2015 for the CW fourteen days after fertilizer application on DOY 135 and lasted until DOY 154 with a peak of 92 g N ha^{-1} day^{-1} on DOY 140 following a major rain event (Figures 2.4b and 2.6). The emissions from the fertilizer application in the CW treatment lasted longer in 2015 compared to 2014 and ended six weeks after N application.

No emission episode occurred in the OW in 2015 that followed the 2014 fall plough down of alfalfa. The maximum flux observed in 2015 was lower than in 2014. The maximum flux was 3.3 g N ha^{-1} day^{-1} on DOY 260 which occurred after wheat harvest (Figure 2.6).

Conventional soybean and OA had no major emission episodes throughout the growing season. The CS did have an episode after harvest and incorporation of residues on DOY 268. A maximum flux of 53 g N ha^{-1} day^{-1} occurred and only lasted four days (Figure 2.6). Organic alfalfa had an emission episode that occurred between DOY 194 and 216 with a maximum peak of 14 g N ha^{-1} day^{-1} possibly caused by rain events of 7 mm, 16 mm, 17 mm, and 4 mm occurring on DOY 194, 206, 209 , and 210, respectively (Figures 2.4b and 2.6).

The alfalfa fall plough down occurred three weeks earlier in 2015 than 2014 and occurred on DOY 246 with a second incorporation occurring on DOY 272 to ensure termination. Low emissions occurred after the fall plough down of alfalfa in 2015 with a maximum peak of 9.2 g N ha^{-1} day^{-1} occurring eight days after the first plough down (Figure 2.6). Slightly greater emissions were observed in 2015 after the plough down possibly due to wetter soil conditions (Figure 2.6).

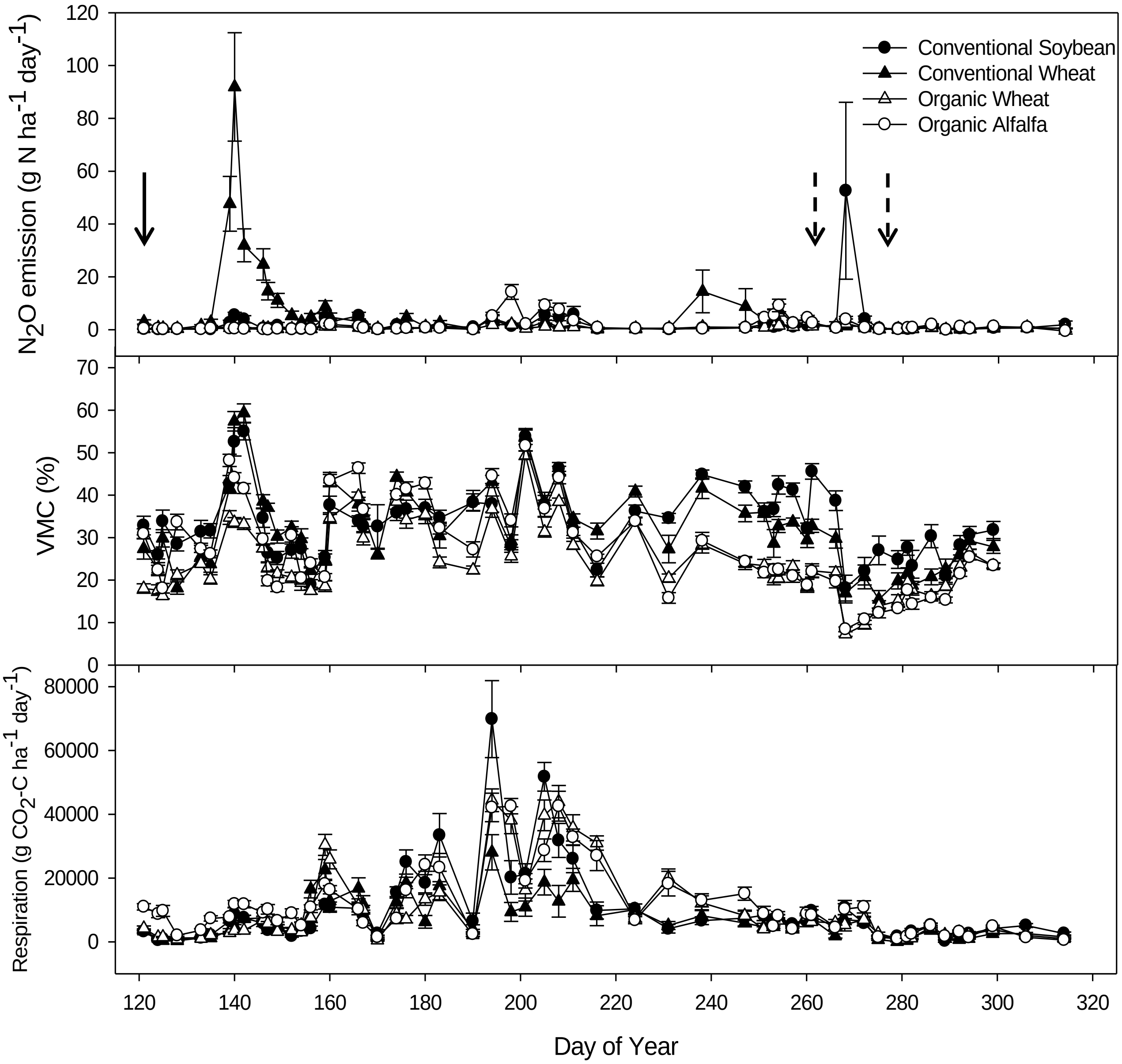


Figure 2.6: Mean daily 2015 growing season nitrous oxide emission rates, soil volumetric moisture content (H_2O cm^{-3} soil) 0-5cm, and respiration rates from conventional soybean, conventional wheat, organic wheat, and organic alfalfa. Bars indicate ± standard error of the mean (n=12). Solid arrow indicates fertilizer application in conventional wheat and dashed arrows indicate alfalfa plough down and cultivation.

Again in 2015, soil VMC were consistently lower in the organic treatments on most dates compared to the conventional however this difference is more prominent later in the season. After the fall alfalfa plough down soil VMC dropped well below all other treatments however was greater in 2015 compared to 2014 (Figure 2.5 and 2.6).

Again in 2015 low CO_2 emissions after the fall alfalfa plough down may have resulted in low rates of nitrification from the mineralized alfalfa residues resulting in the low N_2O emissions.

Cumulative N_2O emissions in 2014 were greatest in CW with an average of 608 g N_2O-N ha^{-1} followed by CS = OW = OA (Table 2.2) however only the CW had significantly different cumulative emissions compared to CS, OW, and OA. Both management and crop had an effect ($P = 0.0103$) on N_2O emissions suggesting that both management and crop type play a major role in the amount of N_2O emitted (Table 2.2). In 2015 greater cumulative N_2O resulted for all crops except for OW. Again in 2015 CW had the greatest cumulative emissions with an average of 916 g N_2O-N ha^{-1} (Table 2.2), but no statistical difference was observed. No statistical difference in 2015 is most likely due to outliers in the data set. Management but not crop had a significant effect of N_2O emission. When combining 2014 and 2015 mean cumulative emissions management, crop, and year had a significant effect on N_2O emissions, however, only a year*crop interaction ($P = 0.0004$) was observed (Table 2.2). The organic system resulted in statistically lower cumulative N_2O emissions ($P < 0.001$) in 2014 and when emissions when both 2014 and 2015 were considered (Table 2.2).

Table 2.2. Mean crop year cumulative N_2O emission (N_2O) means and analysis of variance across for 2014 and 2015.

		N_2O g N ha^{-1}		
Management	**Crop**	**2014†**	**2015**	**Both**
Conventional	**Wheat**	608 ± 99**a**‡	916 ± 157	763 ± 97**a**
	Soybean	196 ± 47**b**	431 ± 110	314 ± 64**b**
Organic	**Wheat**	163 ± 18**b**	157 ± 16	160 ± 12c
	Alfalfa	108 ± 11**b**	313 ± 21	211 ± 25**b**
Conventional		403 ± 69**a**	674 ± 107**a**	538 ± 66**a**
Organic		136 ± 12**b**	235 ± 21**b**	185 ± 14**b**
	Wheat	386 ± 68**a**	536 ± 111	461 ± 65**a**
	Legume	152 ± 25**b**	372 ± 57	262 ± 35**b**
		2014	**2015**	
		269 ± 37	454 ± 95	
		ANOVA *P* value		
Management		< 0.001	< 0.001	<0.001
Crop		< 0.001	ns§	<0.001
Year		—	—	< 0.001
Management*Crop		0.0103	< 0.001	< 0.001
Year*Management		—	—	Ns
Year*Crop		—	—	0.0004
Year*Management*Crop		—	—	Ns

†2014 crop year includes 2015 spring thaw until seeding 11 Mar. to 28 Apr. 2015.
‡ Means ± 1 standard error within a column and row grouping followed by the same letter are not significantly different *P* 0.05.
§ ns, not significant at *P* 0.05.

2.4.3 Soil Nitrogen and Carbon:

There was a definitive response to the application of fertilizer, compost (2014 only) and to plough down of alfalfa in both 2014 and 2015 in soil NH_4^+ and NO_3^- concentrations (Figures 2.7 and 2.8). In CW after fertilizer application both NH_4^+ and NO_3^- rose above all other treatments in 2014 but only NH_4^+ was greater initially after fertilizer application in 2015. Organic wheat had greater NO_3^- concentrations compared to CW immediately after fertilizer application however this was followed by a drop in NO_3^- in OW and a slight increase in NO_3^- in CW (Figure 2.7). In 2015 lower initial concentrations of NO_3^- following fertilizer application possibly due to low nitrification rates occurring from low temperatures in May of 2015 (Figure 2.4b). After the fall alfalfa plough down in both 2014 and 2015 NH_4^+ and NO_3^- concentrations were greater than all other treatments (Figures 2.7 and 2.8). During spring thaw in 2015 OA also had the greatest soil NH_4^+ and NO_3^- concentrations. Compost application in 2014 in the OA treatment resulted in an increase in NH_4^+ but not NO_3^- possibly due to immobilization occurring due to high C content (Appendix).

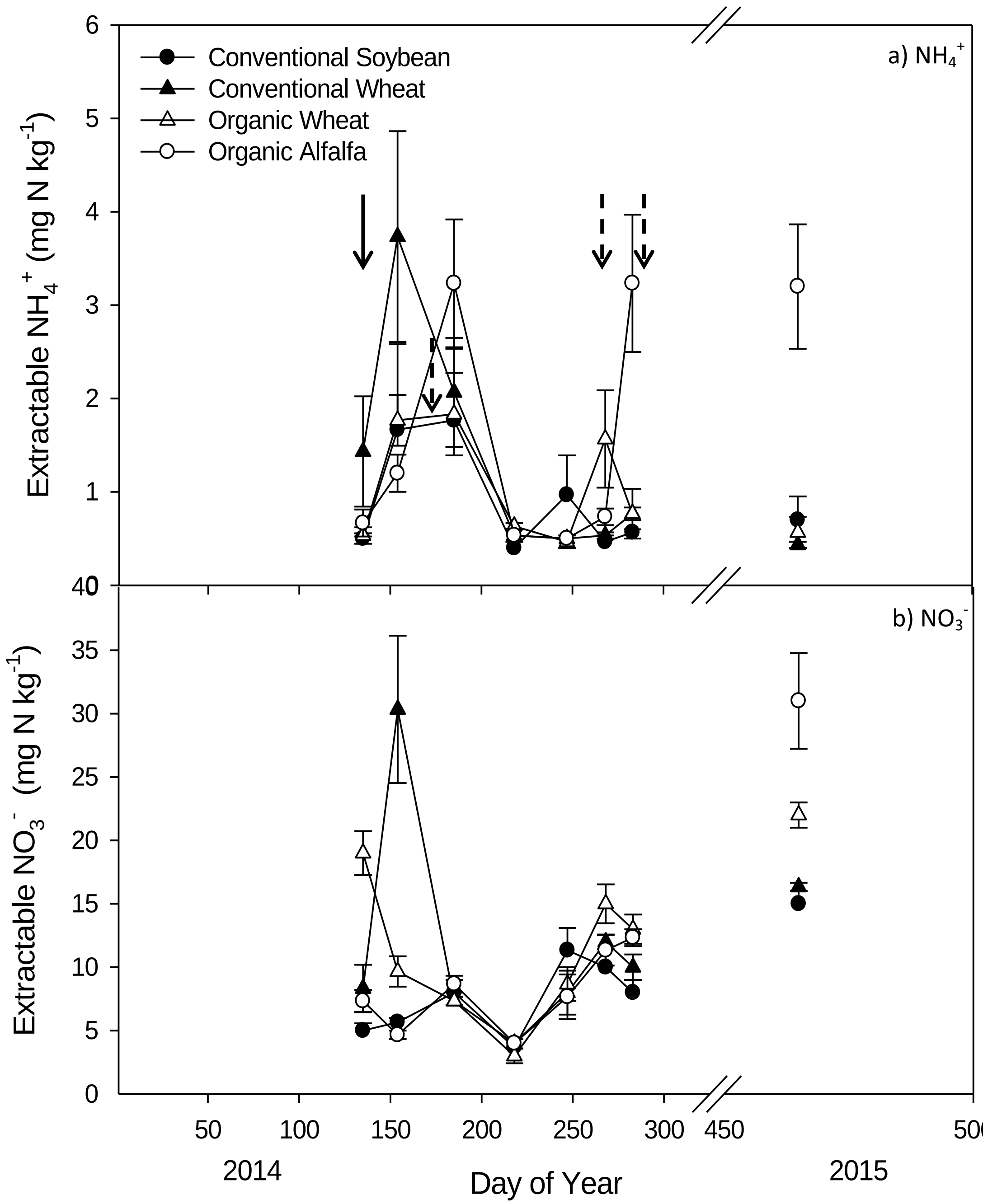


Figure 2.7: Mean crop year (May 2014 – April 2015) extractable soil NH_4^+ (a) and NO_3^- (B) 0-15cm of conventional soybean, conventional wheat, organic wheat, and organic alfalfa treatments. Bars indicated ± 1 standard error of the mean (n=3). Solid arrow indicates fertilizer application in conventional wheat and dashed arrows indicate compost application in alfalfa and alfalfa plough down.

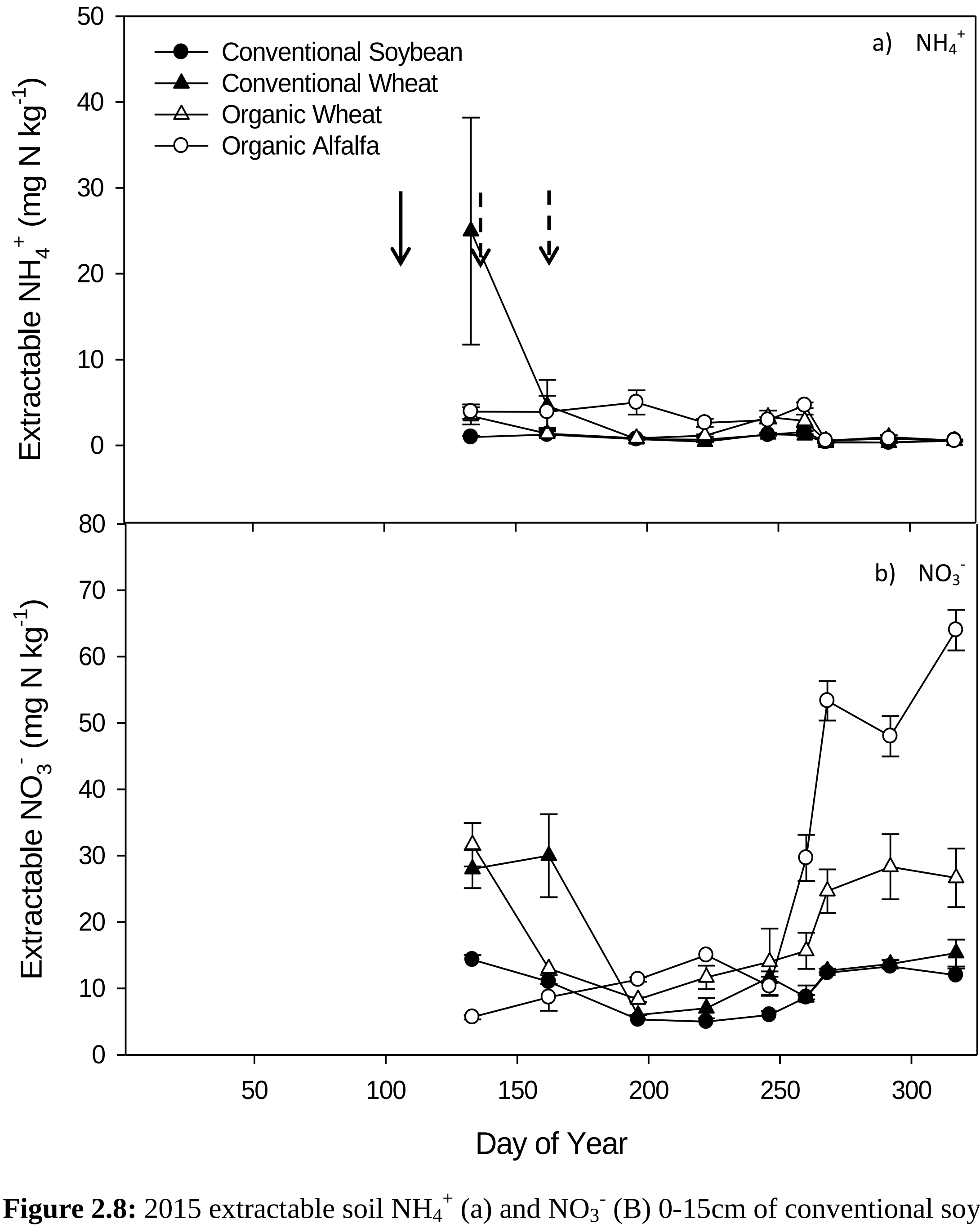


Figure 2.8: 2015 extractable soil NH_4^+ (a) and NO_3^- (B) 0-15cm of conventional soybean, conventional wheat, organic wheat, and organic alfalfa treatments. Bars indicated ± 1 standard error of the mean (n=3). Solid arrow indicates fertilizer application in conventional wheat and dashed arrows indicate alfalfa plough down.

Soil extractable carbon was measured before and after the fall alfalfa plough down in all treatments. In both 2014 and 2015, the organic system had greater total extractable C (TEC) compared to the conventional system (Figure 2.9 and 2.10). During spring thaw in 2014 and spring thaw in the conventional system CW had greater TEC than the CS (Figure 2.9) however in 2015 except for the first sample date (DOY 222) CW and CS had relatively the same TEC content (Figure 2.10). In the organic system in 2014, OW TEC was greater compared to the OW, but after the fall alfalfa plough down TEC in OA treatment rose to equal OW (Figure 2.9). During the 2015 spring thaw period, OW had greater TEC than the OA. In 2015 before the alfalfa plough down OW again had greater TEC content however after the plough down OA TEC content rose above OW and remained above (Figure 2.10).

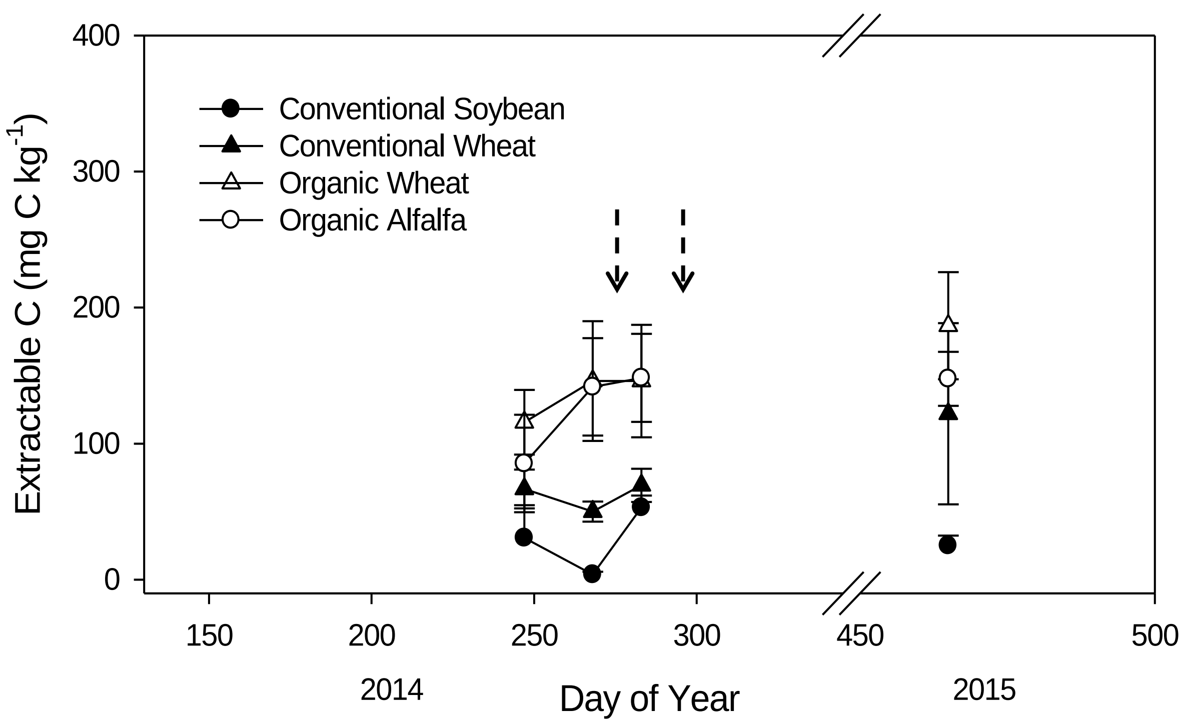


Figure 2.9: 2014- 2015 soil extractable carbon (C) 0-15 cm of conventional soybean, conventional wheat, organic wheat, and organic alfalfa treatments. Bars indicated ± 1 standard error of the mean (n=3). Dashed arrows indicate fall alfalfa plough down.

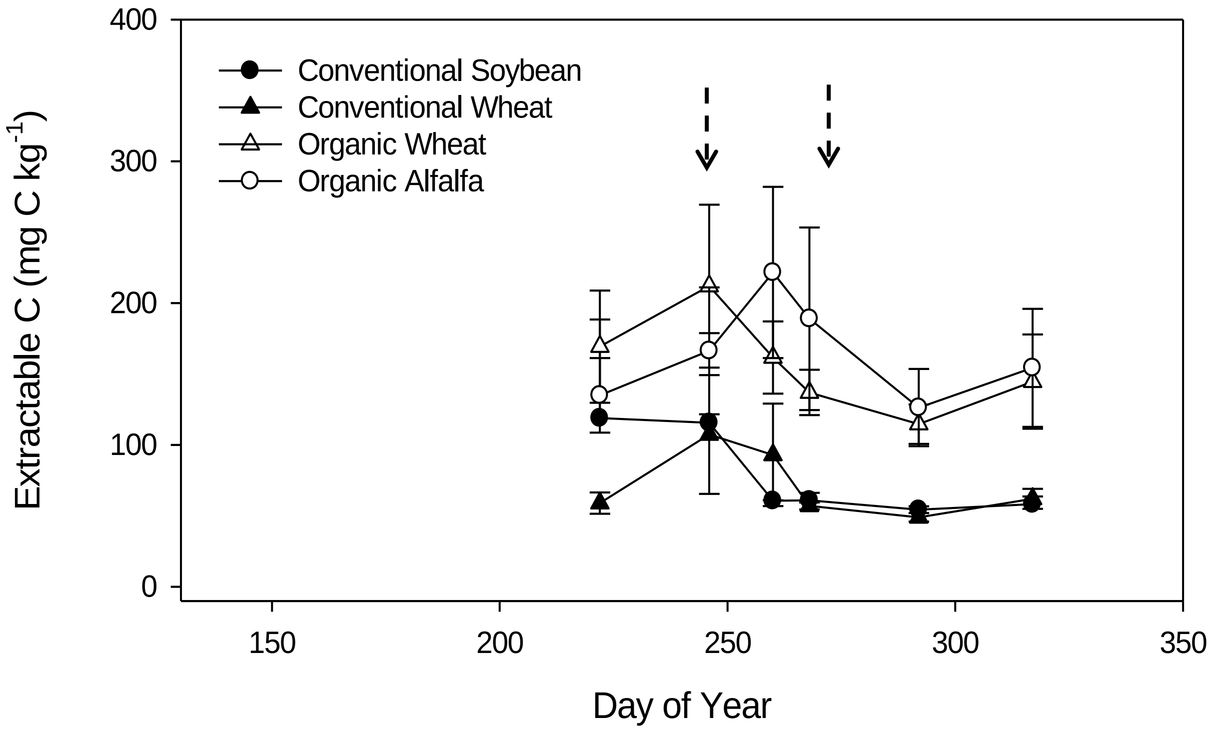
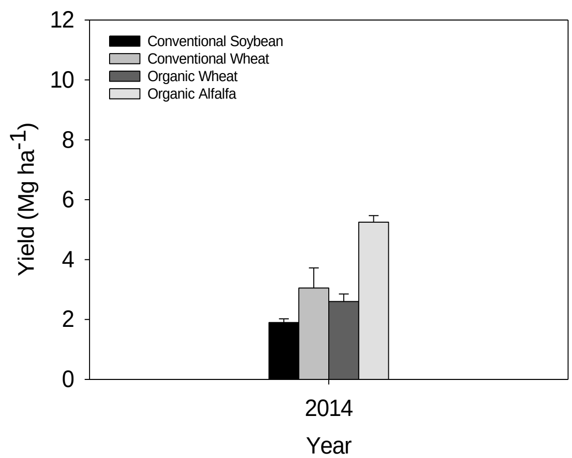


Figure 2.10: 2015 soil total extractable carbon (C) 0-15 cm of conventional soybean, conventional wheat, organic wheat, and organic alfalfa treatments. Bars indicated ± 1 standard error of the mean (n=3). Dashed arrows indicate fall alfalfa plough down.

2.4.4 Crop Response and Emission Intensities

In both 2014 and 2015, CW yield exceeded the 1.2 Mg ha^{-1} 10-yr average for red hard spring wheat Waskada for the area (Manitoba Management Plus Program, Manitoba Agricultural Services Corporation). Organic wheat yield was 15% lower in 2014 (3 vs. 2.6 Mg ha^{-1}) and 50% lower in 2015 (2.9 vs 1.5 Mg ha^{-1}) than the CW yield, but was not statistically different from the OW (Table 2.3). Conventional and organic wheat yields however were lower in 2015 compared to 2014 despite higher seeding rate used (Figure 2.11).

Conventional soybean produced more grain in 2015 compared to 2014 (Figure 2.11). When compared to the 10-yr average of 2.3 Mg ha^{-1}, the CS treatment 2014 yields (1.9 Mg ha^{-1}) were just below the average, but 2015 yield (3.4 Mg ha^{-1}) was above the 10-yr average. Organic alfalfa yields were greater in 2015 compared to 2014 yielding 9.1 Mg ha^{-1} and 5.2 Mg ha^{-1}, respectively. There is no data base for long term organic crop yields so 10 yr averages for the organic treatments in the current study are not possible.



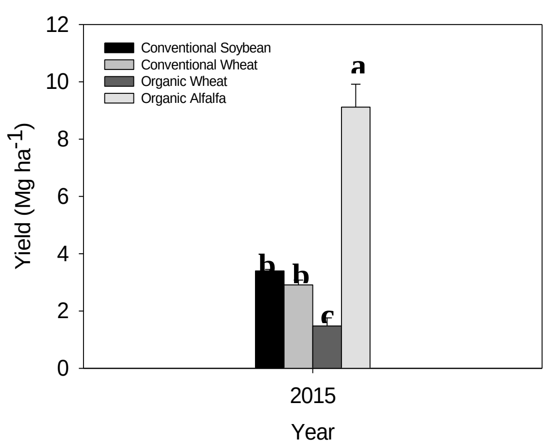


Figure 2.11: Mean yield for conventional soybean, conventional wheat, organic wheat, and organic alfalfa in (a) 2014 and (b) 2015.

Table 2.3. Grain and biomass dry yield, nitrogen removed (N_h), and N_2O emission intensity (EI) of conventional soybean, conventional wheat, organic wheat, and organic alfalfa in 2014 and 2015 (n = 3).

Crop	Yield Mg dry ha^{-1}	N_h kg N ha^{-1}	EI g N kg^{-1}
		2014	
Conventional Soybean	1.90 ± 0.12	106 ± 6	0.10 ± 0.02
Conventional Wheat	3.05 ± 0.67	66 ± 13	0.20 ± 0.03
Organic Wheat	2.60 ± 0.249	56 ± 4	0.06 ± 0.01
Organic Alfalfa	5.25 ± 0.22	146 ± 4	0.02 ± 0.002
		2015	
Conventional Soybean	3.4 ± 0.05**b**	193 ± 3	0.12 ± 0.02
Conventional Wheat	2.91 ± 0.17**b**	79 ± 6	0.31 ± 0.10
Organic Wheat	1.48 ± 0.28**c**	36 ± 9	0.11 ± 0.05
Organic Alfalfa	9.12 ± 0.79**a**	252 ± 16	0.03± 0.001

† Means ± standard error within column.
Note: does not include 2016 thaw data.

Table 2.4: ANOVA table for grain and biomass yield (Mg dry ha¯1) for conventional wheat, conventional soybean, organic wheat and organic alfalfa.

	2014	**2015**
Management	0.0195	0.0037
Crop	0.2096	<0.0001
Management*Crop	0.0057	0.0002

Yield-scaled emission intensity (EI) in 2014 were 0.10, 0.20, and 0.06 N_2O-N kg^{-1} grain for CS, CW, OW, respectively and 0.02 g OA N_2O-N kg^{-1} biomass (Table 2.3). In 2015, EI were greater compared to 2014 with values of 0.12, 0.31, 0.11, and 0.03 g N_2O-N kg^{-1} for CS, CW, OW, and OA respectively (Table 2.3). In both 2014 and 2015, EI were lower in the organic system compared to the conventional system. Conventional wheat had the greatest EI in both years however they were found not to be statistically different from other treatments, again most likely due to outliers in the data set.. Yields were lower in OW than CW for both 2014 and 2015 yet EI were still lower in OW (Figure 2.11). Greater EI in CW was attributed to fertilizer induced N_2O emission episode after urea application (Figure 2.5 and 2.6).

Nitrogen removal (N_h) from the field was significantly greater in both 2014 and 2015 from the legume treatments compared to the wheat treatments most likely caused by alfalfa producing large amounts of biomass (Table 2.3, Figure 2.11 and 2.12). In 2015, legume treatments removed significantly more N from the field than 2014 due to greater yields in 2015 ($P < 0.001$) (Figure 2.11 and 2.12). Nitrogen removal in wheat treatments was not significantly different between 2014 and 2015 (Figure 2.11 and 2.12).

2.4.5 Nitrate Intensity

For both 2014 and 2015, growing season NO_3^- intensity was calculated using linear interpolation to compare $\sum N_2O$ and $\sum NO_3^-$ between conventional and organic treatments (Figure 2.12). In the conventional system NO_3^- intensity was a good predictor of $\sum N_2O$ (r^2 0.56; P 0.0028). In the organic system however; NO_3^- intensity was not a good predicted $\sum N_2O$ emissions (r^2 0.6084; P 0.0029) (Figure 2.12). In the conventional system the greater emissions in the CW may be the cause of the poor NO_3^- intensity predictability for $\sum N_2O$ emissions.

Greater $\sum N_2O$ emissions in the conventional system due to fertilizer induced emission episode in CW resulting in greater amounts of N lost to the atmosphere and not present as NO_3^- in the soil. In the organic system low $\sum N_2O$ emissions occurred and high NO_3^- intensity occurred resulting in greater amounts of NO_3^- within the soil.

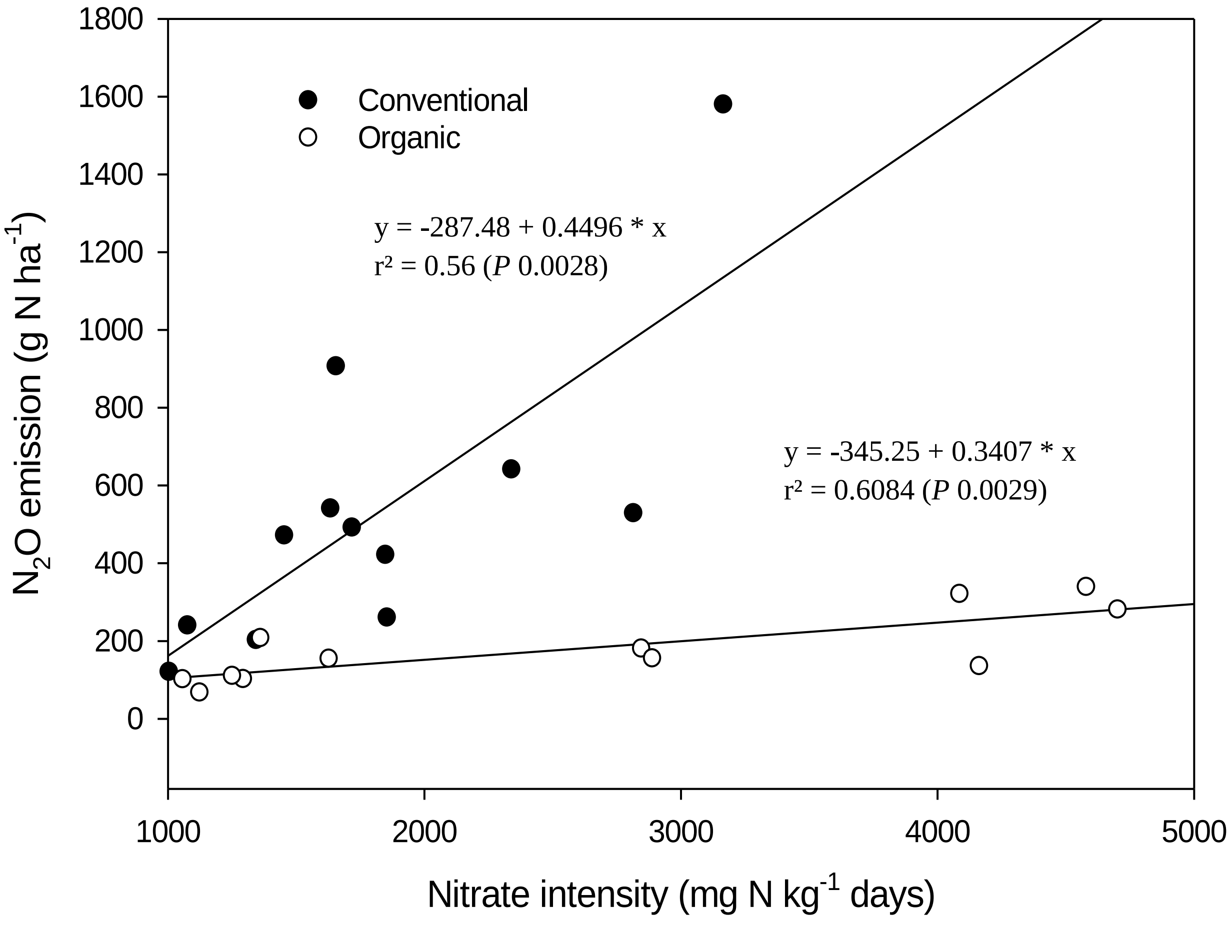


Figure 2.12: Relationship between growing season N_2O emission and nitrate intensity for 2014 and 2015 in between conventional and organic management.

2.5 Discussion and Conclusion

2.5.1 Introduction:

In order to accurately develop GHG inventories and N_2O mitigation strategies precise measurements from all soil management practices must be conducted. A peer-reviewed literature search results in the current study being the first to report N_2O emissions from the fall plough down of alfalfa in organic systems in Canada. The results from this study indicate that the fall plough down of alfalfa in organic system does not produce an N_2O emission episode after the plough down or in the following spring thaw. Low emissions were observed in both 2014 and 2015 in the following crop (hard red spring wheat) in the organic system which received the alfalfa plough down however lower yields were observed.

2.5.2 Nitrous Oxide Emissions:

Conventional wheat N_2O emissions were observed for spring broadcast incorporation applications of urea to spring wheat that has been reported in previous studies (Glenn et al. 2012; Asgedom et al. 2013; Gao et al. 2015). Nitrous oxide emissions were emitted within six weeks of fertilizer application. In 2014 and 2015 peak emissions and cumulative emissions were slightly lower than previously reported (Glenn et al. 2012; Asgedom et al. 2013; Gao et al. 2015).

Soybean N_2O emissions are caused from mineralization followed by nitrification and denitrification from roots and residues from the soybeans and previous crop stimulated by rain fall events (Wagner-Riddle et al. 1997; Maas et al. 2013). No N source was applied to CS due to their capability to biologically fix N causing low emissions, however emission episodes did occur. An episode in 2014 of 64 g N_2O-N/ha/day occurred on DOY 167. This is most likely attributed to past management practices (Synder et al. 2009). The plot was seeded as oats in 2013 and did receive an N fertilizer application. In 2015 an N_2O emission episode occurred after harvest of mature soybeans. A similar observation was made by Rochette et al. (2004) in Ontario. The episode in the present study was most likely caused by release of inorganic N from the soybean residues. This was also preceded by rain events occurring on DOY 259 and 265 which may have stimulated N_2O emissions.

Nitrous oxide emissions observed in the OW and OA treatments were likely due to the mineralization followed by nitrification and denitrification from crop residues, alfalfa root exudates, and from the compost application in 2014 (Rochette et al. 2004; Rochette and Janzen 2005; Maas et al. 2013). The OW treatment in both years showed no N_2O emission episodes from receiving the fall alfalfa plough down. These results are not in agreement with Wagner-Riddle et al. (1997) and Flessa et al (2002) who found that after alfalfa or clover plough downs N_2O emissions tended to increase in subsequent crops. Low emissions may have also been caused by slow mineralization rates of the alfalfa residues due to low moisture conditions during the growing season. In 2014 the GLTCR received less rain than the long-term mean as well as had a lower average temperature. As mentioned, above soil temperature and moisture control inorganic N release from residues which with lower than normal precipitation and temperature may have resulted in low N release in 2014 (Agehara and Warncke 2005). In 2015 Glenlea also received less precipitation than the long term mean however it was a warmer year than the long term average which should have resulted in adequate release of N from the residues. Low emissions in the organic system may have also occurred due to weed competition. Since there is no in-season weed control in organic plots, weeds can compete for the soil N making it unavailable to both the crop and N_2O producing processes (Entz et al. 2014). Immobilization may have also taken place due to greater amounts of C within the organic system making the N unavailable to N_2O producing processes.

It has been reported by Braman (2012) that the organic forage-grain rotation at GLTCR has greater microbial biomass and activity. This may lead to greater N_2O emissions however greater abundance and activity of soil biota does not mean that there is a greater abundance of nitrifying and denitrifying bacteria. The greater abundance could mean greater diversity which may lead to lower populations of nitrifier and denitrifier populations due to competition for resources (Subbarao et al. 2006). Subbarao et al. (2013) states that the reliance of inorganic N fertilizers has shifted agriculture systems to high-nitrifying systems which can also lead to high-denitrifying systems due to the rapid conversion of NH_4^+ to NO_3^- before the crop can utilize large amounts of N. In organic systems inorganic N must first be mineralized before it can be nitrified and denitrified. This can lead to lower amounts of inorganic N within the soil at a particular time during the growing season (Agehara and Warncke 2005; Asedom et al. 2013). Lower amounts of inorganic N could lead to lower amounts of N_2O emitted which was seen in the current study.

It has been reported previously that N_2O emissions from an established alfalfa stand tends to be stimulated by high N contents and rainfall (Wagner-Riddle et al. 1997; Maas et al. 2013). In both 2014 and 2015 the OA had one emission episode occur, however emissions were low and occurred at different times in each year. In 2014 the N_2O emission episode in OA was most likely stimulated by a compost application on DOY 156 which raised the N concentration of the soil which was then followed by rain on DOY 165 and 166. In 2015 the N_2O emissions episode occurred later in the growing season on DOY 197 which was most likely stimulated by rain causing anaerobic conditions conducive to N_2O emissions.

Low emissions after the fall alfalfa plough down in both years are most likely attributed to cooler fall temperatures and low soil moisture contents which are major factors in mineralization of residues and N_2O release (Agehara and Warncke 2005; Ball et al. 2007). Low rates of N mineralization were not the case in this study however due to high cumulative NO_3^- concentrations. Disruption of the soil structure from tillage has been reported to increase N_2O emissions (Coyne 2008). Tillage can cause a breakdown of larger aggregates which allow larger pore space and aerobic conditions into smaller aggregates and smaller pores which causes a more anaerobic environment. This was not the case in the current study. Moisture conditions were low and in Figure 2.3 you can see the amount of large aggregation after the alfalfa plough down. Angers (1991) and Chantigny et al. (1995) reports larger aggregates in soil when alfalfa is planted compared to corn and wheat, respectively. These larger aggregates may have allowed greater infiltration of water through the soil profile causing low moisture conditions in the top 5 cm of soil (Chantigny et al. 1995). Low moisture and temperature may have resulted in low nitrification and denitrification rates due to the slow release of inorganic N into the soil (Ball et al. 2007). However from the soil N results this was not the case since the N were the greatest in the OA treatments, but low emissions still occurred. This finding contradicts Wagner-Riddle et al. (1997), Nadeem et al. (2012), Peterson et al. (2013) and Wallace (2015) who found that after the incorporation of green manure and grass/clover stand produced a N_2O emission episode. However in both the studies ploughing of the green manure and grass/clover stand occurred in the spring which coincides with wetter and warming temperatures. Peterson et al. (2013) followed the termination of the grass/clover with a manure application which may have also contributed to greater emissions observed.

2.5.3 Timing of Alfalfa Plough Down:

The timing of the alfalfa plough down can influence the amount of N_2O that can be emitted as well as how much N will be released to the next crop (Ball et al. 2007; Manitoba Soil Fertility Guide 2007; Wallace 2015). As discussed earlier, soil temperature and moisture heavily influence N release from residues. Depending on the timing of plough down, soil moisture and temperature can vary greatly, especially in temperate places like Canada (Agehara and Warncke 2005; Ball et al. 2007). Ball et al. (2007) conducted a study in Scotland assessing the timing of ploughing organically managed grass/clover swards and found that ploughing of the grass/clover sward in cooler months tended to limit the amount of N_2O produced. Wallace (2015) observed mixed results on timing (fall vs spring) of green manure termination. These differences could be more attributed to the differences in rainfall among the years. In the current study the alfalfa plough down occurred in September in both 2014 and 2015 when soil temperatures began to drop.

Soil moisture content can greatly affect the amount of N_2O released. In the current study low emissions after the plough down of alfalfa was likely due to the drop in soil VMC%. In the CW the N_2O emission episode occurred when soil VMC% was above 25% in both years. In the OA plots soil VMC% after plough down was lower than 25% in both 2014 and 2015. Comparison of soil moisture contents to other studies is difficult due to most studies reporting in water filled pore space. However many studies do agree that N_2O emissions are limited in drier soils (Wrage et al. 2001; Ball et al. 2007). Slightly greater emissions were seen in 2015 which can be attributed to the greater moisture conditions in 2015 or due to year to year variability as reported by Wallace (2015). Greater emissions in 2015 can also be attributed to the earlier plough down of the alfalfa as well.

The earlier plough down in 2015 allowed the alfalfa residues to be exposed to mineralization, nitrification and denitrification longer due to warmer soil temperatures and greater chances of precipitation. Greater NO_3^- concentrations did occur in 2015 however low emissions still occurred. Timing of alfalfa plough down can also affect the amount of N that will be released from the residues to the next crop. Mohr et al. (1997) and the Manitoba Soil Fertility Guide (2007) states that the earlier the alfalfa plough down the more N will be available to the subsequent crop. Greater inorganic N release into the soil may also lead to greater N_2O emission due to warmer soil temperatures and potentially greater moisture contents as observed in Ball et al. (2007). Even with high NO_3^- concentrations low emissions may have occurred due to N being immobilized due to increase in C content of the soil after the plough down.

2.5.4 Spring Thaw N_2O Emissions:

Factors that control spring thaw N_2O emissions are the length of time that the soil is frozen and freeze-thaw events throughout the season (Tenuta and Sparling 2011; Wallace 2015). In 2015 the spring thaw occurred in early March with a quick snow melt and few freeze-thaw events. A total precipitation of 45 mm fell from November 2014 to April 2015. This is lower than the long term average (1981-2010) of 125 mm (Environment Canada 2016).

Low spring thaw emissions occurred in 2015 in all treatments. An average cumulative emission of 10 g N_2O-N ha^{-1} was observed in OA during the spring thaw. Nitrous oxide was measured at Glenlea during spring before fertilizer application (Braman 2012). Braman (2012) also reported lower emissions from the organic forage-grain rotation. In contrast a study conducted by Johnson et al. (2012) found that after fall tillage of second year alfalfa in both organic and conventional systems cumulative spring thaw emissions ranging from 340 – 1540 g

N_2O-N ha^{-1} in Minnesota. In Canada Wagner-Riddle and Thurtell (1998) and Wallace (2015) found greater spring thaw emissions after early and late fall of alfalfa and green manures, respectively. All reports mentioned above resulted in greater N_2O emissions compared to the current study; however both studies have warmer average temperatures and greater precipitation compared to GLTCR. Greater emissions reported in the Johnson et al. (2012) and Wallace (2015) studies could possibly be due to the lighter soil texture. The clay-loam and sandy-loam soil texture may have allowed for not fully saturated conditions more conducive to N_2O producing processes as well as greater gas diffusion to the atmosphere. The heavy clay soil in the current study may have had the opposite effect allowing more anaerobic conditions. This may have allowed denitrification to complete fully to N_2 as well as may have caused lower gas diffusion rates to the atmosphere. Wallace (2015) also reported great year to year variation, which suggests for the current study another spring thaw should be reported.

Soil C has also been reported to affect the amount of N_2O emitted during spring thaw. An incubation study conducted by Tenuta and Sparling (2011) showed greater N_2O emissions in soils with greater C. In the current study the OA treatment had the greatest C content but low emissions occurred. The current contradicted the Tenuta and Sparling (2011) report due to moisture conditions being set to saturated conditions that are most advantageous to N_2O release which may not always be seen in field.

2.5.5 Cumulative N_2O Emissions:

Cumulative N_2O emissions ($\sum N_2O$) observed in CW in the current study (608 and 916 g N_2O-N ha^{-1}) were in range when compared to a studies conducted by Asgedom et al. (2013) and Gao et al. (2015) who showed $\sum N_2O$ emissions ranging from 200 – 2700 g N_2O-N ha^{-1}. Both studies had experimental sites in MB on heavy clay soils and are a good comparison for the current study. Conventional soybean $\sum N_2O$ were slightly lower than a study and review conducted by Rochette et al. (2004) and Rochette et al. (2008) respectively. However these were conducted in eastern Canada which has a warmer and wetter climate possibly resulting in greater N release from residues causing greater N_2O emissions.

Cumulative OW emissions resulted in lower emissions than the CW treatments (Table 2.2). Cumulative emissions in the OW treatment were also lower than studies conducted on organic wheat and other cereals in Minnesota, USA and south east Norway (Johnson et al. 2012; Nadeem et al. 2012). This could be possibly due to differences in crop rotation between studies and differences in application timing and method of manure / slurry / compost applications. Climate could also be another possibility to lower emissions. Johnson et al. (2012) and Nadeem et al. (2012) were conducted in wetter and warmer climates which could have resulted in greater inorganic N release from the organic N sources (Agehara and Warncke 2005).

Cumulative N_2O emissions in the OA treatment were 108 and 313 g N_2O-N ha^{-1} in 2014 and 2015 respectively. In both years OA emissions were lower than emissions reported by Rochette and Janzen (2005) who observed a range of 670 – 4570 g N_2O-N ha^{-1} emissions from alfalfa treatments. Again these studies reviewed however were all located either in Eastern Canada or Eastern United States which receives greater precipitation than MB which may have stimulated greater denitrification rates therefore resulting in greater N_2O emissions (Rochette and Janzen 2005). Maas et al. (2013) conducted a study on N_2O emissions from the forage alfalfa establishment year in the Glenlea, MB area and found a mean range of N_2O emissions of 800 – 1800 g N_2O-N ha^{-1} which is still greater than the current study. Greater emissions are most likely due to past soil management since the site used by Maas et al. (2013) was not under organic management. Johnson et al. (2012) found that fall tilled alfalfa showed high levels of N_2O emissions due to spring thaw. However this was not observed in the current study. Johnson et al. (2012) also found greater cumulative N_2O emissions from a 2nd year alfalfa stand. This study was also conducted in a warmer and wetter climate compared to Manitoba which may have resulted in greater release of inorganic N from the alfalfa residues (Agehara and Warncke 2005; Johnson et al. 2012).

Comparing cumulative N_2O emissions between the organic and conventional treatments in both years the organic treatments produced significantly lower emissions (Table 2.2). This is in agreement with studies conducted by Flessa et al (2002), Petersen et al. (2006) and Aguilera et al. (2013) who found organic systems to emit less N_2O. However studies conducted by Nadeem et al. (2012) and Johnson et al. (2012) showed greater or similar emissions. The organic system had significantly lower yields in Flessa et al. (2002) and Johnson et al. (2012) studies which offset the benefits of lower emissions. Lower yields from OW were also observed in the current study, however lower emissions on a yield-scaled basis were also observed. This study adds to the knowledge that organic cropping systems produce lower N_2O emissions from an area with long cold winters, and short hot summers which differ from the studies mentioned above.

2.5.6 Soil Nitrogen and Carbon:

Inorganic N content of the soil has been noted to be a good indicator of potential N_2O emissions (Asgedom et al. 2013). Following urea application in the CW treatment in both 2014 and 2015 there was a rise in soil NH_4^+ followed by a rise in soil NO_3^- which lead to N_2O emissions. Such a trend has also been reported in previous studies where urea was applied to wheat (Asgedom et al. 2013; Gao et al. 2014; Gao et al. 2015).

The fall plough down of alfalfa also resulted in an increase in soil NH_4^+ and NO_3^- in the OA treatments however this was not followed by an N_2O emission episode. This may suggest that N_2O emission have a seasonal effect with greater N_2O in the warmer and wetter months compared to cooler and drier months despite high soil inorganic N concentrations (Ball et al. 2007; Nadeem et al. 2012). Greater soil C contents have been reported to increase N_2O emissions due to its ability to donate electrons (Li et al. 2005). As mentioned earlier, an incubation study conducted by Tenuta and Sparling (2011) found greater N_2O emissions in soils with greater soil organic matter during spring thaw were observed. However this was not observed in this study. Soil C was greatest in both years and in both organic treatments but there were low N_2O emissions during the growing season as well as during the spring thaw. Greater soil C contents in the organic treatments may have also resulted in immobilization of soil N therefore making it unavailable to be lost as N_2O or the present crop.

2.5.7 Nitrate Intensity:

Nitrogen sources in the current study varied in their N release of NO_3^- which has been reported to be a good indicator for N_2O emissions (Asgedom et al. 2013; Gao et al. 2015). However this was not the case in the OW and OA treatments; early season NO_3^- concentrations were greater in both 2014 and 2015 compared to the CW but no N_2O emission episode occurred. Early presence of NO_3^- is important for short season crops (Asgedom et al. 2013) however yields were lower in the OW despite greater early NO_3^- concentrations. The increase in CW NO_3^- soil concentrations did coincide with an N_2O emission episode in 2014 which was also reported by Asgedom et al. (2013) and Gao et al. (2015) when urea was broadcast and incorporated on spring wheat. Asgedom et al. (2013) found that NO_3^- intensities were related to $\sum N_2O$ emission in rapeseed (*Brassica napus L.*) and wheat. A similar observation was made in the conventional treatments in the current study, however not in the organic system. The organic treatments had the greatest NO_3^- accumulation, but had lower cumulative N_2O emissions than the conventional treatments. This suggests that N_2O is more responsive to NO_3^- intensity in conventional systems and not in organic where other factors may play a bigger role. However only four cumulative NO_3^- values in the organic system were much greater than the conventional system; another study should be conducted to see if this pattern will reoccur.

High NO_3^- intensity and low $\sum N_2O$ in the organic treatments may be possibly due to the occurrence of immobilization causing the NO_3^- to be unavailable to N_2O producing processes due to the greater amounts of C within the treatments (Subbarao et al. 2006). Tenuta and Sparling (2011) found greater N_2O emissions with greater soil C, however soil conditions were made saturated conducive to N_2O release. A study conducted by Braman (2012) at the GLTCR found greater microbial biomass and activity in the perennial organic plots. This greater biomass and activity may have resulted in greater diversity and greater competition for soil N sources also making the NH_4^+ / NO_3^- unavailable. Li et al. (2012) reported greater abundance of *Proteobacteria* in the organic treatments at the GLTCR which include nitrifying and denitrifying bacteria (Coyne 2008; Norton 2008). Subbarao et al. (2006) reported nitrifiers being poor competitors in soils with high amounts of organic matter.

2.5.8 Yield and Yield Scaled N_2O emissions:

When comparing organic and conventional agriculture systems it is important to compare yields between the different management systems because lower yields can offset the positive environmental impacts (Johnson et al. 2012). Yield in organic systems are reported to be on average 30% lower than conventional systems which are in agreement with the current study

(Stanhill 1990; Hoeppner et al. 2005; Pimentel et al. 2005; Goh 2011). In 2014 the OW had 15% lower yield and was not statistically different. In 2015 the OW had up to statistically significant lower yields of up to 50%. Economically certified organic grain receive price premiums for their crop which may make up the difference between the yields, but with a growing population the lower yields observed may not be able to satisfy the needs (Stanhill 1990; Pimentel et al. 2005; Johnson et al. 2012).

Protein content of hard red spring wheat is an important factor to consider in order obtaining the highest economic return for the crop. The threshold to obtain the greatest economic return is a protein content of 13.5% (Manitoba Soil Fertility Guide 2007). In 2014 CW had a protein content of 13.5% and the OW had a lower protein content of 12%, but organic premium prices may still offset the lower protein content economically. In 2015 both the CW and OW had protein contents 17% and 15% respectively and therefore would both get the greatest economic return for their crop.

Lower yields in the OW, which received the 2013 and 2014 fall plough down of alfalfa may have been due to the low N supplying power from the alfalfa residues. The Manitoba Soil Fertility Guide (2007) indicates that a full alfalfa stand that is terminated in fall will supply approximately 50 kg N/ha to the subsequent crop. Agehara and Warncke (2005) and Ball et al (2007) found N release from organic residues to be dependent on the soil environment mainly due to soil moisture and temperature conditions. In 2015 soil moisture contents were greater than 2014 throughout the growing season however this did not result in equal or greater yields in the OW treatment. Soil NO_3^- was the highest the after the plough down of alfalfa in both 2014 and 2015, but may not have been a sufficient amount of N to supply the subsequent crop (Pimentel et al. 2005). Lower yields may have also been a result to greater weed competition due to no weed control during the growing season in organic cropping systems.

Organic alfalfa yields were in range of yields reported in a survey conducted by Entz et al. (2001) on 14 organic farms across the Canadian prairies. Yields were also in range with a review conducted by Rochette et al. (2004) on alfalfa stand in eastern Canada on conventional farms and harvested three times a year compared to only two in the current study. Therefore low yield and biomass may not have been responsible to the low emissions in the OA and OW.

It has been reported that organic systems can equal or out-yield conventional systems (Stanhill 1990; Entz et al. 2001; Pimentel et al. 2005). Pimentel et al. (2005) conducted a comparison study and found that when comparing wheat and soybean yields between organic and conventional systems was found to be similar in South Dakota and at the Rodale Institute. Entz et al. (2001) compared yields and soil statuses on 14 organic farms, many of which included forages such as alfalfa, and found that in some years that organic yields can almost double that of conventional systems. It has also been reported that in years of drought and stress, organic systems will tend to have greater yields and consistent yields due to their greater water holding capacity and infiltration rates (Seufert et al. 2012). An important note for the majority of the organic systems that out-yielded conventional systems were that the ones that contained legume-based forages as a part of their rotation which is practiced in the forage-grain organic rotation at GLTCR (Entz et al. 2001). An energy efficiency study conducted by Hoeppner et al. (2005) on the Glenlea Long-Term Rotation study site over a 12-year period found the forage-based organic system to be the most energy efficient, but did not have a greater energy output than the conventional system. However when the alfalfa forage was converted to live animal weight gain energy there was no statistical difference in energy output (Hoeppner et al. 2005).

Yield scaled emissions (EI) are useful to show how different N sources produce different amounts of N_2O per unit of grain / biomass (Asgedom et al. 2013). Yield scaled emissions were greater for all treatments in 2015 compared to 2014 and ranged from 0.01– 0.33 g N kg^{-1}. The OA treatment was 10x lower when compared to the CS in both 2014 and 2015. This is most likely due to greater biomass production in OA resulting in less N_2O emitted per kg of harvested material. Organic wheat in 2014 had a greater difference in EI to CW compared to 2015 where the EI was approximately 50% lower. The greater EI in the OW treatment in 2015 is most likely due to lower yields which resulted in greater amounts of N_2O lost per kg of grain. This has been reported to be the major cause of increases in EI in organic systems (Johnson et al. 2012). Johnson et al. (2012) and Flessa et al. (2002) found organic systems having greater EI compared to conventional systems. Nadeem et al. (2012) found EI for the amount of N_2O emitted per kg of N harvested in grain to be greater in organic systems using grass-clover green manure (95 vs 47 g N_2O-N kg^{-1} N yield) when comparing organic and conventionally grown barely. This was not the case in the current study: the OW treatment had less N_2O emitted per kg of N_h and per kg of grain harvested compared to the conventional counterpart. However the studies mentioned had greater N_2O emissions overall.

2.5.9 Comparison of the Glenlea Rotation to Organic Farms on the Canadian Prairies:

A review conducted by Entz et al. (2001) showed that there are three main rotations in Canadian organic farms and consist of i) grain-only, ii) rotations with green manures, and iii) rotations with perennial forages. Crops included in organic systems in the Canadian prairies include forages, cereals, oilseeds and pulses (Entz et al. 2001). The Glenlea Long-Term Crop Rotation is a typical rotation in the Canadian Prairies including a forage legume such as alfalfa, followed by spring wheat and then followed by an oilseed such as flax. In a review conducted by

Thiessen Martens et al. (2015) organic systems now contain a much wider variety in their rotations sometimes including agro-forestry and annual poly-culture. In the review conducted by Entz et al. (2001) found that the most commonly grown crop after alfalfa or sweet clover (*Melilotus spp*) stands was spring wheat which is also done in the GLTCR. Organic wheat yields in the current study are in agreement with the Entz et al. (2001) review of 14 organic farms that saw a range of 672 – 2690 kg ha^{-1} from 119 field observations. Termination of forage legumes on organic farms include practices such as incorporation / plough down of residues such as in this study, by grazing of cattle, or both (Entz et al. 2001; Ball et al. 2007). As mentioned, this study does convey what a typical Manitoba organic farm would look like and has been under organic management for 24 years. Nitrous oxide emissions from the OA, the OA fall plough down, and OW treatments would be representative.

2.5.10 Conclusion:

The current study provides much needed information on soil N_2O in organic cropping systems in the Canadian Prairies since no studies have yet been conducted. With annual increases in land under organic management it is important to accurately quantify N_2O emissions of all soil management systems. The current study reported lower N_2O emissions in the organic treatments compared to the conventional in both 2014 and 2015, not considering 2016 thaw emissions. No N_2O emissions episode occurred after the fall plough down of alfalfa in both years. No N_2O emission episode occurred during the 2015 spring thaw period after the fall alfalfa plough down. The use of alfalfa as an N source in organic cropping systems could be used as an N_2O mitigation strategy in the Red River Valley resulting in lower amounts of N_2O emitted per ha and per kg of grain. However yields of subsequent crops such as hard red spring wheat are needed to increase to be able to feed a growing population.

3.0 General Discussion and Conclusion:

3.1 Contribution to Understanding from the Glenlea Long-Term Crop Rotation:

The Glenlea Long-Term Crop Rotation was established in 1992 and is in its 25th year. This long term site has allowed it to be used for many research questions between these organic and conventional cropping systems. Research questions that have been studied included looking at soil nutrient dynamics including both N and P (Welsh et al. 2009; Bell et al. 2012), the soil food web (Braman 2012; Briar et al. 2012; Li et al. 2012), energy efficiency (Entz et al. 2004; Entz et al. 2005; Hoeppner et al. 2005), and economics (Entz et al. 2014).

Under organic management phosphorus (P) is an issue due to reliance on high P demanding crops such as alfalfa. Welsh et al. (2009) found that plant available P was depleted but not recalcitrant P under organic management; however this study was conducted before a modest compost rate was applied. Bell et al. (2012) reported soil C, N, and P was lower in the organic forage rotation compared to the conventional annual rotation. The quality of hard red spring wheat was compared between the two systems and found that the organic forage produced wheat had comparable mineral concentration to the conventional (Turmel et al. 2009). Soil health has become an intensively researched question and has been studied at GLTCR looking at mycorrhizal colonization (Entz et al. 2004), microbial activity and abundance (Braman 2012), as well as nematode populations (Briar et al. 2012). Entz et al. (2004) reported that flax under organic management had greater mycorrhizal colonization (Figure 3.1). Briar et al. (2012) found lower enrichment of nematodes but greater population structure in the organic rotation. Briar et al. (2012) mentions that in a rotation with a green manure crop there were greater abundances of fungal feeding nematodes which indicate slow decomposition and helps prevent nutrient loss

(Figure 3.1). Braman (2012) reported soils under organic management had great microbial activity and microbial biomass in the forage-grain rotation (Figure 3.1). However no study has been conducted on comparing GHG between organic and conventional systems in Canada or at the GLTCR study site.

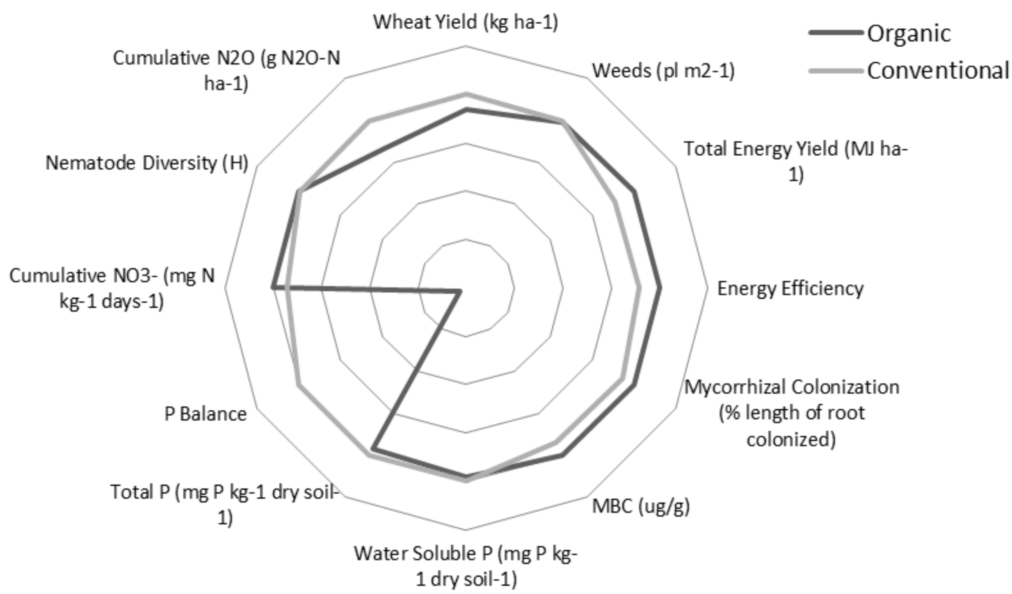


Figure 3.1: Effect of crop rotation and management systems on wheat yield (kg ha^{-1}), weed density (pl m^{-1}), total energy yield (MJ ha^{-1}), energy efficiency, Mycorrhizal colonization (length of root colonized (%)), microbial biomass content (ug g^{-1}), water soluble P (mg P kg^{-1} dry soil), total P (mg P kg^{-1} dry $soil^{-1}$), P balance, cumulative NO_3^- (mg N kg^{-1} days), nematode diversity (H index), cumulative N_2O emissions (g N_2O-N ha^{-1}). In all cases center of the graph is 0. Assumptions for spider diagram in Table 3.1.

Table 3.1: Assumptions behind spider diagram (Figure 3.1).

Parameter	Maximum (outer ring)	Minimum (inner ring)	Notes
Wheat Yield (kg ha^{-1})	3,647	0	Current study
Weeds (pl m^{-1})	1,839	0	Entz et al. 2014
Total Energy Yield (MJ ha^{-1})	960,065	0	Hoeppener et al. 2005
Energy efficiency	16	0	Hoeppener et al. 2005
Mycorrhizal Colonization (% length of root colonized)	79	0	Entz et al. 2004
Microbial Biomass Content (ug/g)	2,291	0	Braman 2012
Water Soluble P (mg P kg^{-1} dry soil)	17	0	Welsh et al. 2009
Total P (mg P kg^{-1} dry soil)	460	0	Welsh et al. 2009
P Balance	44	0	Welsh et al. 2009
Cumulative NO_3^- (mg N kg^{-1} days)	4,123	0	Current study
Nematode Diversity	3.3	0	Briar et al. 2012
Cumulative N_2O (g N_2O-N ha^{-1})	718	0	Current study

Much attention has been placed on N_2O mitigation strategies and knowledge of N_2O emissions from all soil management practices (Smith et al. 2007; Goh 2011; Johnson et al. 2012). The current study supplies valuable additional information to the GLTCR site on N_2O emissions between organic and conventional cropping systems. In both 2014 and 2015 the organic treatments emitted less N_2O compared to the conventional (Figure 2.5 and 2.6) and aids in highlighting the environmental benefits from organic management (Figure 3.1). This study can aid in encouraging farmers to adopt beneficial and organic management practices due to the high demand for N_2O mitigation. However yields in organic systems need greater research. This work is currently being conducted by Entz et al. (2015) conducting a participatory wheat breeding program for Canadian organic farmers. After three years found that the farmer selected varieties were able to out yield the conventional counter parts. Fully understanding all aspects of alternative management systems is important to develop more sustainable and ecological farming systems that do not cause an economic loss (Thiessen Martens et al. 2015). Long term rotation studies sites like the GLTCR can provide accurate and first-rate data to answer all the questions mentioned above.

3.2 Environmental Benefits of Organic Cropping Systems:

As mentioned one major criticism of organic cropping systems is lower yields which may not be able to sustain a growing population (Smith et al. 2007; Johnson et al.2012). It has been reported that in years of drought and stress organic systems tend to produce more stable yields, which in a changing climate would be beneficial (Seufert et al. 2012). In spite of lower yields, organic systems offer many other environmental benefits.

Environmental benefits in organic agriculture systems include greater C sequestration in soil, lower energy requirements due to the absence of N fertilizer, herbicides and pesticides and in turn lower input costs, greater microbial activity, increased soil health, increased biodiversity, and greater job opportunities (Hoeppner et al. 2005; Pimetal et al. 2005; Braman 2012; Thiessen-Martens et al. 2015). The current study adds to the benefits of organic cropping systems in Canada reporting low N_2O emissions on an area basis and per unit of grain compared to the conventional comparison.

A life cycle assessment conducted by Pelletier et al. (2008) found that if Canada was to switch from current conventional methods to organic methods for corn, wheat, canola, and soybean found many positive benefits. Pelletier et al. (2008) found that switching would reduce energy consumption in agriculture by 0.8%, acidifying emissions by 1%, and global warming emissions by 0.6%. However there was no difference in the amount of ozone-depleting emissions which N_2O does contribute to. The current study found much lower N_2O emissions in organic systems in Canada. This finding may be used in future assessment which may lead to a different conclusion and find further reductions in global warming and ozone-depleting emissions.

3.3 Yields and Energy use in Organic Cropping Systems:

When comparing organic and conventional systems grain yield and energy output are important factors to consider (Smith et al. 2007; Johnson et al. 2012). On average organic yields are about 30% lower compared to conventional systems however in some studies organic systems can out yield conventional systems (Hoeppner et al. 2005; Pimentel et al. 2005; Goh 2011). This was observed in the current study in 2014, but in 2015 yields were approximately 50% lower in the OW (Figure 11). The lower N_2O emissions in this study may be offset by the lower yields in the organic treatments even though it was found not to be statistically different. As mentioned in the previous chapter organic systems have out yielded conventional systems and have greater yield consistency under stress and droughts (Seufert et al. 2012). Also as mentioned research is taking place on improving yields in organic systems which could make organic systems a greater competitor with conventional yields (Entz et al. 2015).

Energy use between organic and conventional systems is reported to be different with energy use being lower in organic systems (Hoeppner et al. 2005; MacRae et al. 2010). One of the major contributors to this difference is due to the production and transportation of N fertilizer used in conventional systems (Hoeppner et al. 2005). In studies comparing organic and conventional GHG and or N_2O emissions the GHG emitted from the production and transportation of N fertilizer are rarely included (Flessa et al. 2002). The inclusion of the GHG produced during fertilizer production would increase the amount of GHG emitted per unit of grain in conventional systems. A comparison N_2O study of organic and conventional systems conducted by Flessa et al. (2002) did include GHG from the production of N fertilizer and still found organic systems to emit greater GHG but this was mainly attributed to the low yields.

An area that has had little attention when discussing yields in agricultural systems is the area of food waste and consumption. MacRae et al. (2010) reported food waste during processing and found that up to 40% of what is grown is lost. However not all that was thrown out was considered edible for humans, but could have possibly been used for either animal consumptions or used as soil amendments (MacRae et al. 2010). Less food waste during processing could allow organic systems to be able to compete with conventional systems for growing food on the same amount of land. Consumption and dietary preferences have also increased and changed in the last few decades (MacRae et al. 2010; Davidson et al. 2014). MacRae et al. (2010) reported that North Americans are now consuming on average 3500 kcal/day which is much higher than the recommended 2200 kcal/day. A report by Davidson et al. (2014) found that reduced food waste and sensible protein consumption could decrease a consumer's N footprint by approximately 39%. These areas are difficult to discuss and accurately define however with greater education and outreach for reducing food waste and sensible consumption, organic production may be possible to feed the growing population.

In the current study, the organic treatments had both lower N_2O emissions and lower EI compared to the conventional treatments but yields were lower in both years. A review on energy use at the GLTCR found that the perennial organic rotation, the rotation used in this study had the best energy use efficiency out of the four rotations in the study (Hoeppner et al. 2005). With lower N_2O emissions, energy use, and greater conscience eating efforts this may offset the lower yields in organic systems. This study adds valuable information in addition to finding lower N_2O yield scaled emissions (amount of N_2O emitted per unit of grain) in organic systems compared to conventional systems. Reducing both energy use and N_2O emissions in agriculture would be a step in the right direction to reduce GHG emissions from agriculture.

3.4 Organic Crop Production as a N_2O Mitigation Strategy in Agriculture

In recent years there have been many strategies in conventional systems to reduce soil N_2O emissions from agriculture. Strategies include the beneficial management practices, the 4-Rs (right place, right time, right source, and right rate), inhibitors, and enhanced efficiency fertilizers (Davidson et al. 2014). Many studies have been conducted on how the strategies mentioned above have reduced soil N_2O emissions (Liu et al. 2013; Asgedom et al. 2013; Halvorson et al. 2014; Gao et al. 2015). It has also been suggested that organic agriculture could be a mitigation strategy (Smith et al. 2007). Cumulative emissions in the studies cited above ranged from 0.16 – 4.49 kg N ha^{-1}. In the current study cumulative N_2O emissions in OW that received the fall plough down of alfalfa were 0.16 kg N ha^{-1} in both years. In both years the OW were equal to or lower than the lowest value reported by Liu et al. (2013), Asgedom et al. (2013), Halvorson et al. (2014), Gao et al. (2015) for enhanced efficiency fertilizers, and other N_2O mitigation practices. This study has showed that organic systems that rely on alfalfa for nutrients could be used to develop potential N_2O mitigation strategies for Manitoba agricultural systems.

3.5 Organic and Conventional Crop Production Trends and Implications to N_2O Emissions

In Canada there are 65,000,000 hectares (ha) of land under agriculture production (Statistics Canada 2011). In the past decades there has been an increasing trend for consumer preference towards organic products. The total amount of land under organic production in Canada in 2009 was just over 700,000 ha and increased to 900,000 ha in 2014 (Agriculture & Agri-Food Cananda 2013; Canadian Organic Trade Association 2016). With increasing ha of land under organic production this may impact the amount of N_2O emitted from agricultural systems.

It is currently estimated that 70% of anthropogenic N_2O emissions are caused by N fertilizer applications to soil (Environment Canada 2016). A search for peer-reviewed papers on N_2O emissions in organic systems showed little research in Canada. This implies that the calculated 70% of N_2O emissions from soil came from conventional agricultural systems. Due to the differences in soil management between organic and conventional systems the amount of N_2O emitted may be different.

In the current study the organic system produced considerably less N_2O than the conventional system on an area and yield scaled basis. If current trends continue with greater land converted to organic agriculture this may lower the amount of N_2O emitted and overall GHG from agriculture in Canada (Pelletier et al. 2008; MacRae et al. 2010). However further research is needed; Wallace (2015) reported greater cumulative N_2O emissions than the current study after the incorporation of green manures in Atlantic Canada from October to May ranging 260 - 1220 g N_2O-N ha^{-1}. Cumulative emissions reported in the current study and by Wallace (2015) are still lower than emissions reported for conventional systems (Glenn et al. 2012; Asgedom et al. 2013; Gao et al. 2013; Gao et al. 2015).

There has been great progress in reducing N_2O emissions from conventional systems with the use of the 4-Rs and enhanced efficiency fertilizers. One of the 4-Rs as mentioned above is “Right Place” meaning the placement of the fertilizer can help control N_2O emissions. Millar et al. (2010) reported banding or nesting of N fertilizer in the soil reduced N_2O emissions compared to broadcasting. Gao et al. (2013) and Halvorson et al. (2013) found that a controlled release urea product ESN reduced N_2O emissions by nearly half. The inclusion of legume crops in conventional systems also has the potential to decrease N_2O emissions. Legume crops such as soybeans produce their own N through biological nitrogen fixation and do not need N fertilizer applications. Under a changing climate however these results may change as well. Release of N from the concentrated fertilizer bands or from the polymer-coated urea relies on soil microbiota, temperature and moisture conditions.

It is estimated that an increase in global temperature of 2 to 4.5 °C with a change in precipitation patterns in the upcoming decades (IPCC 2007). An increase in temperature in Manitoba may lead to greater N_2O emissions from both conventional and organic systems due to change in freeze-thaw patterns and increased growing season. Projected climate data compiled using the Canadian Global Circulation Model by Mbogga et al. (2009) estimates that Manitoba mean annual temperature will increase 1.6 to 3.2 °C by 2020. Mbogga et al. (2009) also reported little change in mean annual precipitation; however greater precipitation events are predicted to occur during the summer months. With increasing temperatures an increase in central Manitoba due an increase in agriculture land is suggested to occur (Mbogga et al. 2009). Increased land use for agriculture may lead to an increase in N_2O emissions if mitigation practices are not set.

Yields may also be affected in a changing climate. Qian et al. (2013) using the CERES-Wheat Model projects an increase in yield and biomass for the Canadian Prairies. An increase in temperature and land under cultivation may lead to an increase in N_2O emissions in conventional and organic systems. However with greater yields this may offset the increased N_2O emissions. Qian et al. (2013) also reported a shortened growing season by 10 days attributing it to the warmer temperatures which would speed up the maturity process.

Longer growing seasons and shorter times for cash crop production are suggested by both Mbogga et al. (2009) and Qian et al. (2013). Longer growing season may allow for the practice of planting catch crops after harvest. Termination of catch crops however can induce N_2O emissions which may increase the amount of N_2O from agriculture (Li et al. 2014; Ball et al. 2007). Increased temperatures and a longer growing season may also affect freeze-thaw and spring thaw events possibly contributing to greater N_2O emissions as reported by Wagner-Riddle et al. (1997). Warmer temperatures may also cause a change in crop rotation for MB, such as including corn and other warm season crops. This may increase or decrease the amount of N_2O emitted depending on N demands of the crop.

Greater land converted to organic management systems may lead to less N_2O emissions from agriculture in Manitoba. However in a changing climate N_2O emissions from organic systems may be closer to what is reported by previous studies mentioned above, all of which were conducted in warmer and wetter climates than the current study. Conventional systems are at risk for increased N_2O emissions in the future if more land is suitable for agriculture in Manitoba. However with greater adoption of the 4-R strategies, inhibitors, enhanced efficiency fertilizer and possibly organic management practices, conventional systems may have reduced emissions in the future.

3.6 Surprising Observations

During the study some unexpected surprises did occur. In both 2014 and 2015 the OW emerged before the CW treatment despite being seeded on the same day and receiving no N application. Lower bulk density can create easier conditions for roots and emerging shoots to move through the soil (Stolze et al. 2000). Stolze et al. (2000) mentions good root growth is favoured with greater spatial and chemical availability of nutrients. This is stimulated by microbial activity, which Braman (2012) reported in the organic system at GLTCR. Another interesting discovery was that the CW treatment started senescing before the OW, however the OW fully matured before the CW. Organic wheat may have completed senescence before the conventional possibly due to lower amounts of N in the tissue and grain (13.5 and 17 vs 12 and 15% protein content).

The low emissions observed after the fall plough down of alfalfa, during spring thaw and in the subsequent crop were also surprising finding. Wagner-Riddle et al. (1997) and Flessa et al (2002) reported emission episodes after incorporation of alfalfa, during spring thaw and the subsequent crop. Wagner-Riddle et al. (1997) reported an emission episode of up to 1000 g N_2O-N ha^{-1} $month^{-1}$ after alfalfa incorporation and during spring thaw emissions greater than 1000 g N_2O-N ha^{-1} $month^{-1}$ over multiple months. The current study observed an average cumulative emission of 10 g N_2O-N ha^{-1} from the 2015 spring thaw. Despite low emissions, there was greater NO_3^- in the alfalfa treatments during spring thaw and greater cumulative NO_3^- in the organic system. Asgedom et al. (2013) and Gao et al. (2015) both reported greater NO_3^- intensities with greater N_2O emissions which were the opposite from the current study.

In 2014 and 2015 the emission episodes that occurred in the CS treatment was surprising, especially because no fertilizer N had been applied. Snyder et al. (2009) reported that N2O emissions may occur in crops such as soybeans that do not receive fertilizer applications from the residual N that was applied to the previous crop. The 2014 episode may have been stimulated by residual N left from the previous crop which was at Glenlea was oats that did receive an N fertilizer application (Snyder et al. 2009). The emission episode in the CS after the 2015 harvest was surprising because there were lower emissions observed in the OA, but had greater amounts of residues. Emissions after soybean harvest are also reported by Rochette et al. (2004) stating that soil disturbance causing mineralization of the soybean residue releasing inorganic N resulting in N_2O emissions. In the current study, harvest was followed by a rain event stimulating N_2O emissions (Wagner-Riddle et al. 1997; Maas et al. 2013).

3.7 Recommendations for Future Research:

Future research is needed due to year to year variability of N_2O emissions (Wallace 2015). Research on the use of green manures, and different crops planted after forage alfalfa which could cause different amounts of N_2O release. Different manure / compost applications at different times of the year or in rotation should also be monitored. Understanding N_2O emissions from different organic rotations due to advances in organic crop rotations would also be an asset as well as researching why N_2O is released differently from organic systems (Thiessen Martens et al. 2015). As mentioned many times in the current paper greater research on improving yields in organic systems which are now being conducted (Entz et al. 2015). Future research could also be conducted on looking at using alfalfa in conventional systems by reducing the amount of N fertilizer need in the following crop. This however could lead to greater N_2O emissions as documented in Wagner-Riddle et al. (1997) and Flessa et al. (2002) after the ploughing of alfalfa and in the subsequent crop.

3.8 Conclusions:

Organic agriculture offers many benefits to not only the environment but to farmers and producers themselves for reasons stated above. However greater research is needed to increase yields in organic cropping systems which is now underway. With greater adoption of organic practices agriculture can be well on its way to reducing its environmental footprint and reduce the amount of GHG emissions. Nitrous oxide is one important GHG to mitigate from agriculture due to approximately 70% of anthropogenic N_2O produced is from agricultural soil (Environment Canada 2016). Studies currently conducted on N_2O emissions comparing organic and conventional systems show organic systems emitting greater or lesser N_2O emissions than conventional systems. The Glenlea Long-Term Crop Rotation and Management study site has once again served and answered an important research question for comparing and understanding the difference between organic and conventional management. The current study did not detect an N_2O emission episode after the fall plough down of alfalfa in organic systems, during the spring thaw, or in the subsequent crop (spring wheat). Lower cumulative emissions in both organic alfalfa and wheat compared to the conventional soybean and wheat treatments on an area basis as well as on a yield scaled basis (N_2O per kg of grain) despite lower yields were observed.

Appendix:

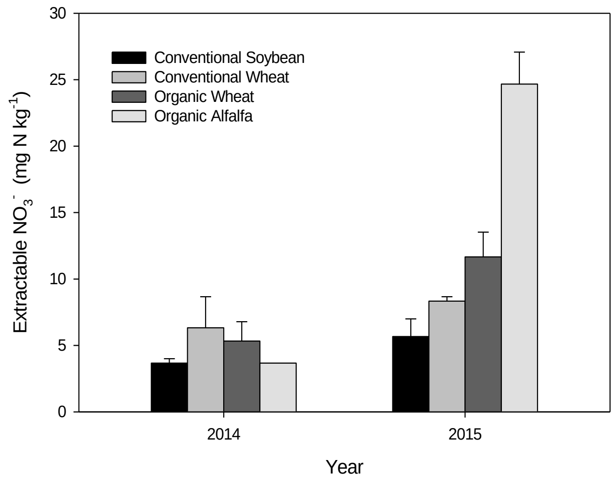


Figure 4.1: 2014 and 2015 extractable soil NO_3^- (mg N kg^{-1}) 15-60 cm of conventional soybean, conventional wheat, organic wheat, and organic alfalfa treatments. Bars indicated ± 1 standard error of the mean (n=3).

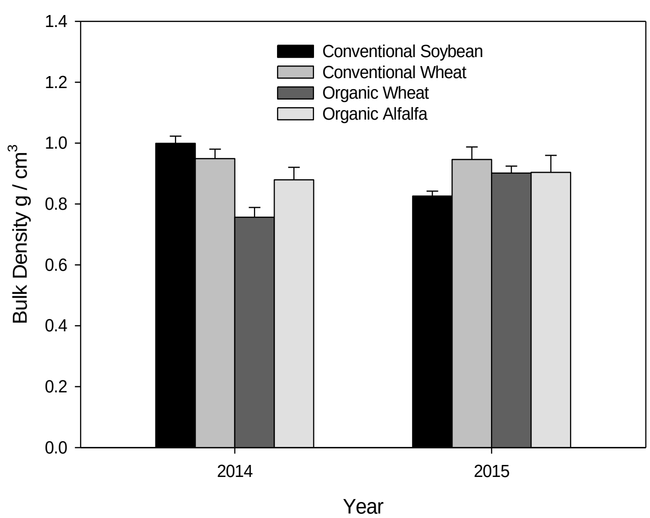


Figure 4.2: 2014 and 2015 soil bulk density g/cm^3 in the top 5 cm of conventional soybean, conventional wheat, organic wheat, and organic alfalfa treatments. Bars indicated ± 1 standard error of the mean (n=6).

	Dry Basis	As Received	lbs/ ton
Total Nitrogen (N):		0.58 %	14
Ammonium Nitrogen:			
Nitrate Nitrogen:			
Inorganic Nitrogen:			
Organic Nitrogen:			
Phosphate (P2O5):	0.91 %	0.35 %	7.0
Potash (K2O):	3.9 %	1.5 %	30
Sodium:	0.33 %	0.13 %	2.6
Calcium:	1.8 %	0.67 %	13
Magnesium:	0.74 %	0.29 %	5.7
Zinc:	95 ppm	37 ppm	0.073
Iron:	6176 ppm	2376 ppm	4.8
Manganese:	416 ppm	160 ppm	0.32
Copper:	26 ppm	10.0 ppm	0.020
Sulfur:	0.55 %	0.21 %	4.2
Chloride:			
pH:			
Salts:			
Total Carbon:			
Volatile Solids:			

Figure 4.3: Agvise compost analysis for compost applied in organic alfalfa in 2014.

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